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SPECTRAL REFLECTANCES OF COMMON MATERIALS IN THE ULTRAVIOLET REGION

By M. Luckiesh

With the increasing interest in ultraviolet radiation, particularly in respect to life and to health, the spectral output of sources and the spectral transmission and reflection of materials correspondingly increases in importance. The output of known sources and the transmission of common substances are now fairly well known;[1] however, much less data is available pertaining to the spectral reflection characteristics of common substances. Reflectance is measured with greater difficulty and less certainty, and, of course, there is a far greater number of reflecting substances than transparent materials.

During many years of work with ultraviolet radiation, the writer has studied the reflectance of a large number of substances for radiation of various wave lengths. For the most part these measurements have been made by the tedious and not very accurate photographic method. Recently, with the development of the photoelectric cell and of the more common energy-measuring instruments technique can be simplified and results can be more accurate. However, with experience the photographic method yields results sufficiently accurate for most practical purposes. This is the more recognizable when one considers the generally greater individual differences between reflecting specimens of the same material than in the case of transparent substances. With reasonably careful technique perhaps the photographic method may be considered to yield results sufficiently accurate for most pur-

[1] Spectral Characteristics of Light-Sources and Window Materials Used in Therapy, W. W. Coblentz; Trans. I.E.S., *23*, p. 247; 1928.
Ultraviolet Radiation, M. Luckiesh; D. Van Nostrand Co., New York, 1922.
The Chemical Action of Ultraviolet Rays, Ellis and Wells; Chemical Catalogue Co., 1925.

poses; but better methods may now be developed very readily in a well-equipped laboratory.

Scattered here and there throughout the scientific literature spectral reflectances of materials are to be found. Among those who investigated common materials of general interest is Hurlburt[2] who presented data pertaining to about two dozen metals throughout the ultraviolet region down to λ1800 (Angstrom units). No attempt will be made here to gather these data together for they have been abstracted by the writer in the publication already referred to. Since the data of that publication no work has come to his attention which includes a large array of reflecting materials. Therefore, data are presented

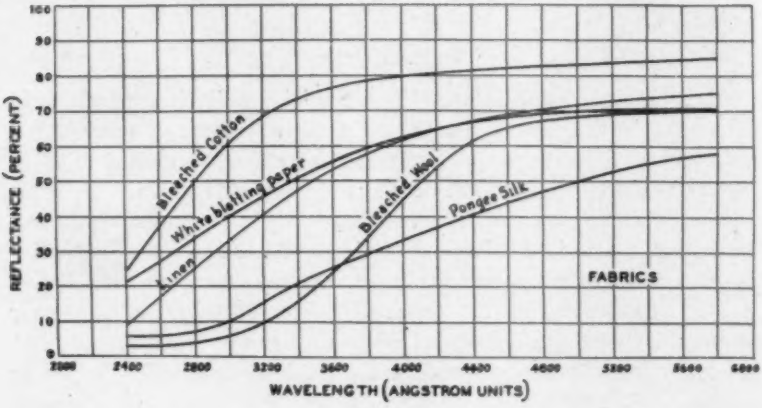

FIG. 1.

herewith pertaining to a variety of materials of more or less practical interest in the general use of ultraviolet. The data are presented in graphic form because of the obvious advantage. Furthermore, the degree of accuracy of the data scarcely warrants tabulated values of spectral reflectance.

The spectral reflectances of some common fabrics are presented in Fig. 1. Bleached cotton appears to be much superior in reflectance, throughout the major portion of the ultraviolet region, than silk, wool or linen. The spectrum of solar radiation reaching the earth's surface practically ends at λ2900. Therefore, for protection against ultraviolet radiation outdoors and particularly in the tropics white cotton

[2] The Reflecting Power of Metals in the Ultraviolet Region of the Spectrum, E. O. Hurlburt; Astrophysical Journal, *42*, p. 205; 1915.

should be appreciably superior to other common fabrics with white linen ranking next and above bleached wool or pongee silk. White blotting paper has a lower reflectance in the ultraviolet than in the visible region.

A few representative dry white pigments were examined for various specific purposes. The reflectance of zinc oxide is seen in Fig. 2 to be particularly low—practically zero—for ultraviolet radiation of shorter wave lengths than λ3800. Any observer who has photographed white pigments with ordinary plates or films is aware of the difference in reflectances of so-called whites. It is particularly interesting to photograph white lead and zinc oxide on adjacent areas. Among these

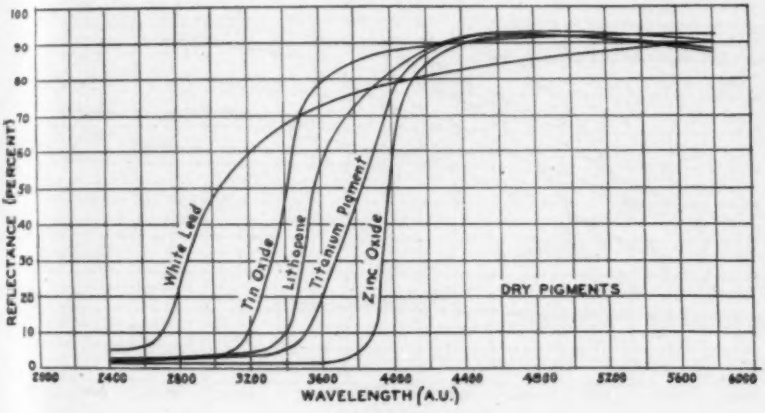

FIG. 2.

common dry white pigments it is seen that white lead is superior as a reflector of ultraviolet radiation in the region of current interest between λ2800 and λ3200. The other whites can not qualify where high reflectance is desirable in this spectral region. In cases where a high reflectance is desirable in the visible region and absorption of ultraviolet is necessary zinc oxide is particularly attractive.

In Fig. 3 the spectral reflectances of other dry powders are presented. Magnesium carbonate, slaked lime, wall plaster, kaolin and aluminum oxide have fairly high reflectances in the ultraviolet region which should find some uses in special or even in commercial applications. Pulverized silica also has a high reflectance. Graphite continues to exhibit a low reflectance in the ultraviolet as it does in the visible.

From data in Figs. 2 and 3 it is possible to choose the desirable

pigments for paints and enamels where reflection and absorption of ultraviolet are to be considered.

Data pertaining to a few commercial paints are presented in Fig. 4. Here the vehicle exhibits its influence. Ordinary aluminum paint is the best reflector of ultraviolet radiation in this group. Bronze paint has a low reflectance as would be expected on examining the data for the metals of which it is composed.

At this point it may be interesting to compare the spectral reflectance of porcelain enamel (Fig. 5) with those of dry white pigments and powders and also of paints. The "glass" character of the surface of porcelain enamel naturally contributes most toward the absorption of

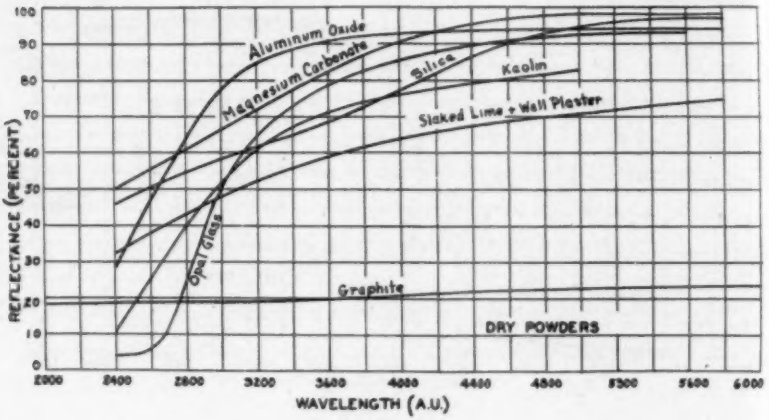

FIG. 3.

ultraviolet energy shorter than λ3200. It is well known that ordinary glasses are practically opaque to energy of shorter wave lengths than this. In cases of porcelain enamels where such a glaze or "vehicle" is used the pigment is of consequence in the spectral region of wavelengths longer than λ3200. In this connection Figs. 2 and 3 are of interest.

In Fig. 5 data are presented for more or less common metals. It is seen that chromium and aluminum have the highest reflectances in the ultraviolet and that there is little choice between them. In the region of short-wave ultraviolet—below λ3200—polished chromium is somewhat superior to polished aluminum. However, we find differences in the reflectances among specimens of the same material in the visible region. Perhaps this is true in the ultraviolet. Generally

the reflectance of chromium is less than that of aluminum for visible radiation. Zinc, steel and nickel have fairly high reflectances throughout the ultraviolet and may be considered favorably for reflectors where their special qualities are attractive in practical applications. On the other hand, the reflectances of tin are quite low throughout the ultraviolet although they are fairly high in the visible region. Silver exhibits an interesting minimum just below λ3200 which a number of years ago led to an interesting suggestion for the use of a thin film of silver as a special filter. Porcelain enamel has been commented upon. Doubtless it would be improved by giving special attention to the ingredients—both the flux and the pigment. At

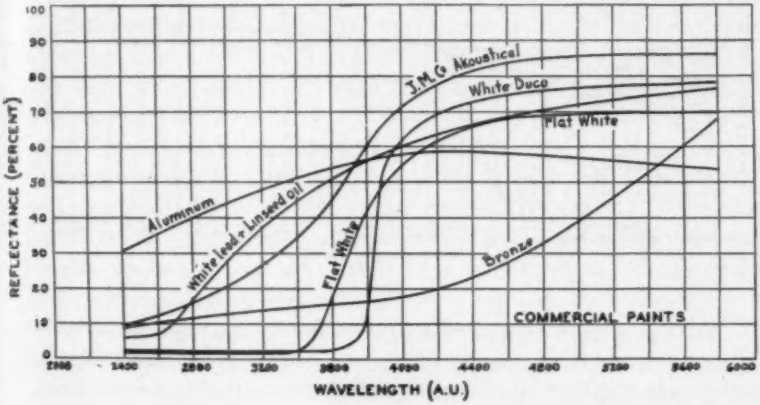

FIG. 4.

present it is a very inferior reflector for ultraviolet radiation of wavelengths shorter than λ3200.

Hurlburt's data for antimony indicate practically the same reflectances as those exhibited by aluminum. Platinum and cobalt are in the class with nickel, zinc and steel. Gold and copper only moderately reflect ultraviolet radiation as might be expected. Hurlburt also found that the reflectances of tungsten and molybdenum were of moderate values and those of tantalum were lower. Recently, Coblentz and Stair[3] have published new data pertaining to a number of metallic surfaces and also included data obtained by others. In the case of a few of the metals included in Fig. 5 the curves include the

[3] Reflecting Power of Beryllium, Chromium and Several Other Metals, Coblentz and Stair; Bureau of Standards Journal of Research, *2*, p. 343; 1929.

influence of data presented by Hurlburt and by Coblentz and Stair. In these cases the curves are compromises which are sufficiently representative for practical purposes.

Besides these acknowledgements, credit is due Mr. L. L. Holladay of this Laboratory for obtaining the complete data for thirty of the materials discussed and partial data for some of the metals.

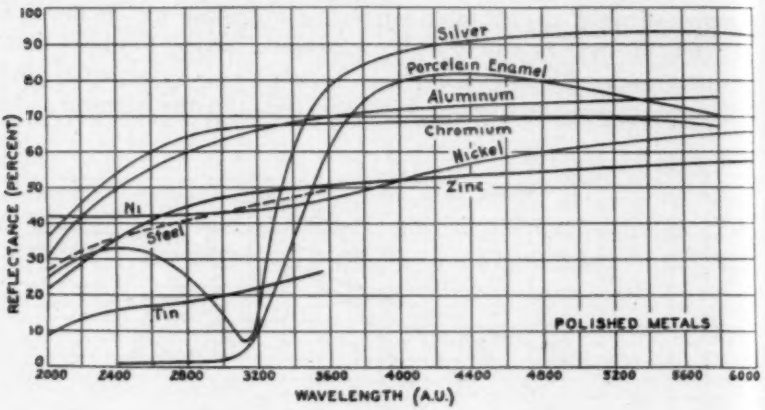

FIG. 5.

The use of such data pertaining to common materials is not entirely confined to the development of efficient reflecting surfaces. Sometimes it is desirable to utilize the spectral absorption characteristics to eliminate radiation of certain spectral ranges. When artificial lighting-practice reaches the stage of combining with lighting for seeing specific radiations for the preservation of health, spectral reflecting characteristics of materials will be of great importance. The data pertaining to materials which have been presented herewith are already of utmost importance in outdoor life and in special uses of ultraviolet radiation from artificial sources. They also represent a substantial beginning of the necessary accumulation of data for the additional function of artificial lighting which appears to be in the offing.

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A METHOD OF OBTAINING THE OPTICAL CONSTANTS OF METALLICALLY REFLECTING SUBSTANCES IN THE INFRARED

By C. Boeckner

The method of obtaining the optical constants described in this paper consists in the measurement of the reflecting power of light (polarized in the plane of incidence) at two angles of incidence. A computation based on the Fresnel reflecting power formula then gives the optical constants; *i. e.*, the index of refraction and the extinction coefficient. The method is applicable to amorphous substances and to unaxial crystals. In the latter case, however, only the "ordinary" reflecting power formula is derived. The method is applied to fused and crystalline quartz for wave lengths in their bands of metallic reflection at 8μ.

The usual katopric method for obtaining these constants has not been applied to the infrared owing to the difficulty of constructing a polarizer and analyzer usable in this wave-length region. Nichols has succeeded in calculating the index of refraction of quartz for wave-lengths up to the reflection bands from measurements on absorption and normal reflecting power.[1] He could not penetrate the region of metallic reflection, however, owing to the impossibility of getting thin enough films.

Part of the object of the research was to investigate the marked change of reflecting power with change of angle of incidence observed by Gorton[2] and to see if this effect could be explained by the usual reflecting power formulas.

EXPERIMENTAL

The ratio of reflecting power of quartz to silver was measured, absolute reflecting power was not attempted.

Polarization of the light was brought about by means of a selenium mirror according to the method described by A. H. Pfund.[3]

The apparatus is shown diagrammatically in Fig. 1. A Nernst filament *A*, a concave mirror *B*, and the selenium mirror *C* are mounted on an arm of the spectrometer *D*. A supporting arrangement for the

[1] Nichols; Phys. Rev., *4*, p. 297; 1896.
[2] A. F. Gorton, Phys. Rev., *7*, p. 66; 1916.
[3] A. H. Pfund, Phys. Rev., *22*, 362; 1905.

quartz mirror E is mounted on the spectrometer table. The arm and the table can rotate independently, thus enabling the beam EF to the spectrometer S to be kept stationary for all angles of incidence of the light on the quartz.

The path of the light is as follows: Light from the filament A is rendered parallel by the mirror B. This parallel beam is polarized by C so that its direction of polarization is horizontal. The beam, perpendicular to the axis of rotation, falls on the vertical mirror E, is reflected to the fixed mirrors F and G and brought to focus on the slit H of the spectrometer S.

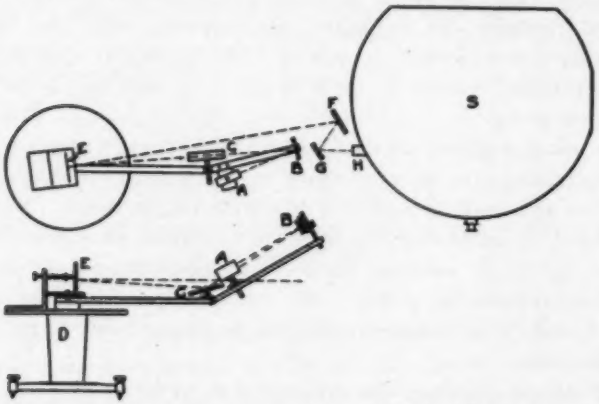


FIG. 1. *Arrangement for measuring reflecting power of polarized light for various angles of incidence in the infrared.*

The spectrometer is a rock salt instrument of moderate resolving power. The radiation was measured at the exit slit by means of a vacuum thermopile and a Leeds and Northrup galvanometer, sensitivity about 400 megohms. The angle of incidence was changed by rotating the spectrometer table through a known angle and rotating the arm BAC so that the filament image remained on the slit.

Measurements were made at 5° and 68° as angles of incidence. The silver mirror was prepared by chemical deposition of the silver on the glass, and its normal reflecting power taken from tables. The reflecting power at 68° was taken to be 99%. The mirrors were held against three fixed points in the usual way in order that the silver and the quartz surfaces could be accurately interchanged.

Stray light in the spectroscope was corrected for by obtaining the transmission of a very thin quartz bulb. The slight reading, about 1%, in the region of metallic reflection was taken to be the stray light. The effect of stray light was also diminished by the use of a glass shutter which is opaque to the 8 u region.

A slit width correction described by Hyde[4] was also applied. These corrections usually cancelled, amounting in the total to about 1%. They were not applied in all cases since they were of the order of magnitude of the experimental error.

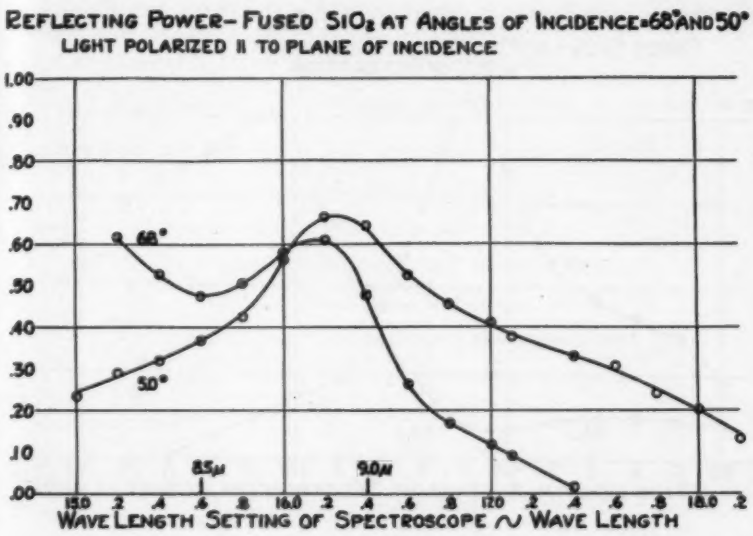


FIG. 2. *Reflecting power fused SiO_2 light polarized ∥ plane of incidence.*

The maximum deflection obtained amounted to about 5 cms for 100% reflection on the galvanometer scale. This fact caused an uncertainty of about 1 or 2% in the results since readings could not be taken closer than 1/2 mm.

The selenium mirror was adjusted to its polarizing angle by use of the fact that the vertical quartz mirror should completely extinguish the horizontally polarized light from the selenium at the polarizing angle of incidence of the quartz.

In the case of crystalline quartz a reflecting surface parallel to the

[4] Hyde, Astro Phys., *35*, p. 237; 1912.

optic axis must be used and the plane of incidence of light must be perpendicular to this axis.

THE FRESNEL FORMULAS

The Fresnel formula for the reflection of light polarized in the plane of incidence is:

$$A = \tan(\theta - r)/\tan(\theta + r), \tag{1}$$

where

A is the amplitude for unit amplitude of incident light, θ the angle of incidence, r the angle of refraction and n the index of refraction.

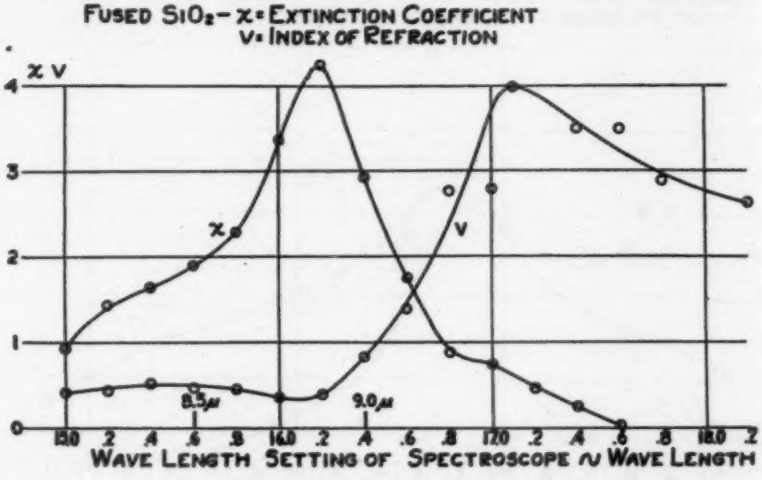


FIG. 3. *Extinction coefficient and index of refraction fused SiO_2.*

For an absorbing medium n is complex, $n = v(1 - ix)$, where v is the index of refraction, and x is the extinction coefficient.

For the purpose of the experiment it is desired to find the absolute value of A since this is what is measured.

Quincke gives a first approximation to A valid for large values of vx[5]

$$A^2 = (v^2(1+x^2)\cos^2\theta - 2v\cos\theta + 1)/(v^2(1+x^2)\cos^2\theta + 2v\cos\theta + 1) = R$$

where R is the fraction of the incident energy reflected.

From this relation the computation of v and x from measurements of the reflecting power at various angles of incidence is simple. If R_m

[5] Winkelmann, Handbuch der Physik; 2 Aufl., p. 1300.

is the minimum reflecting power and θ_m the angle for minimum reflection, then

$$1+x^2=(1+R_m)/(1-R_m), \tag{2}$$

and

$$v=[1/\cos\theta_m][(1+R_m)/(1-R_m)]. \tag{3}$$

It was found, however, that the Quincke approximation did not represent the experimental results. This was found to be due to v being a small quantity, thus making vx in most cases less than one.

The exact expression for the absolute value of A in equation (1), however, was found to give results in agreement with the measurements. A comparatively simple expression for A can be found in the following way:

Let $1/n=(1/v)(1/v)/(1-ix)(1-ix)=Fe^{is}$, then

$$A=\tan(\theta-r)/\tan(\theta+r)=(\sin 2\theta-\sin 2r)/(\sin 2\theta+\sin 2r).$$

Let $r=a+ib$ then,

$$A=\frac{\sin 2\theta-\sin 2a\cosh 2b-i\cos 2a\sinh 2b}{\sin 2\theta+\sin 2a\cosh 2b+i\cos 2a\sinh 2b},$$

$$A^2=R=\frac{(\sin 2\theta-\sin 2a\cosh 2b)^2+(\cos 2a\sinh 2b)^2}{(\sin 2\theta+\sin 2a\cosh 2b)^2+(\cos 2a\sinh 2b)^2}$$

$$R=\frac{\cosh^2 2b+\sin^2 2a-\cos^2 2\theta-2\sin 2\theta\sin 2a\cosh 2b}{\cosh^2 2b+\sin^2 2a-\cos^2 2\theta+2\sin 2\theta\sin 2a\cosh 2b}. \tag{4}$$

To find a and b

$$\sin r=\sin(a+ib)=\sin\theta/n=F\sin\theta e^{is}$$

or

$$\sin a\cosh b+i\cos a\sinh b=F\sin\theta\, e^{is}.$$

Equating real and imaginary parts we have

$$\sin a\cosh b=F\sin\theta\cos s, \qquad \cos a\sinh b=F\sin\theta\sin s.$$

On solving for sina, cosh b

$$\sin a=(A-B)/2 \tag{5}$$

$$\cosh b=(A+B)/2 \tag{6}$$

Where

$$A^2=1+F^2\sin^2\theta+2F\sin\theta\cos s \tag{7}$$

and

$$B^2=1+F^2\sin^2\theta-2F\sin\theta\cos s. \tag{8}$$

It was found after the computations had been completed, that Drude

has given an exact form of the reflecting power formulas.[6] The above form is somewhat more convenient for the purposes of the computations, however,

By examination of equations governing reflection from crystals it is found[7] that Equation (1) applies to light reflected from a uniaxial crystal provided the light is polarized in the plane of incidence and provided the plane of incidence is perpendicular to the optic axis. The constants found will be those of the ordinary ray. Reflection at other surfaces involves hopeless complications in the formulas.

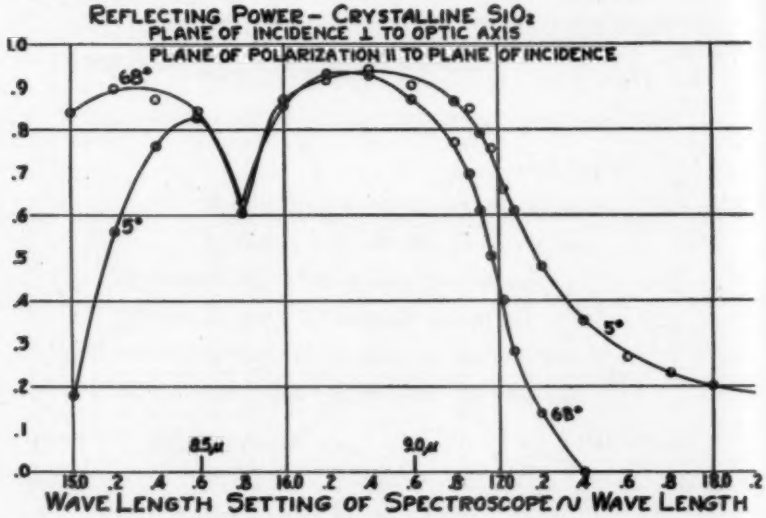


FIG. 4. *Reflecting power crystalline SiO_2 plane of incidence perpendicular to optic axis light polarized perpendicular to plane of incidence.*

Light polarized perpendicular to the plane of incidence can not be used in the case of an isotropic solid as its reflecting power varies too little with the angle of incidence to offer an accurate means of calculating v and x.

METHOD OF COMPUTATION

It, of course, is impossible to solve these equations explicitly for x and v. It was therefore necessary to resort to the method of trial and error. A value of F was assumed, cos s was then calculated from the reflection power at normal incidence by the relation

[6] Ann. der Phys., u. Chem., *35*, p. 520; 1888.
[7] J. Walker; Analytical Theory of Light.

$$\cos s = [(1+F^2)/2F][(1-R)/(1+R)].$$

A and B were then computed from (7–8) and sin a and cosh b obtained from equations (5–6). The reflection power at the oblique angle of incidence (68°) was then calculated from equation (4). A single such trial required about twenty minutes. It was found that two trials were usually sufficient to determine the F giving the observed reflecting power at the oblique angle of incidence. v and x are then obtained by the relations:

$$1+x^2 = 1/\cos^2 s \quad v = \cos s/F.$$

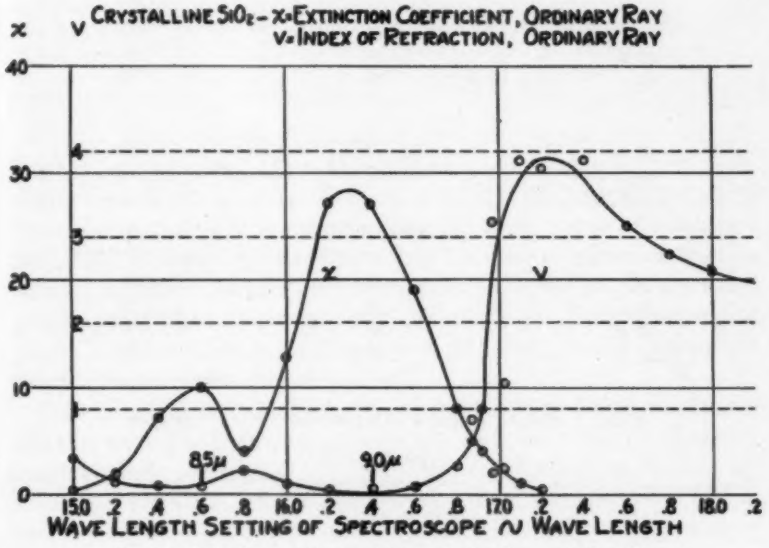


FIG. 5. *Extinction coefficient and index of refraction crystalline SiO_2.*

ACCURACY OBTAINABLE

By examination of the Quincke approximation formula it was found that most accurate values of v and x are obtained by using measurements at normal incidence and at an angle as oblique as possible. An inherent disadvantage in the method is that an error in the calculated v and x is of the order of magnitude in the measured quantity $1+R/1-R$; if R is 95% a 1% error in measurement makes a 20% error in the calculated result. For fused silica, however, where the reflecting power does not go over 70%, a 1% error causes about a 4% error in the result.

RESULTS

The curves for the reflecting powers of fused and crystalline quartz are given for the two angles of incidence 5° and 68°. The wave lengths were obtained by assuming the reflecting maxima of crystalline quartz to occur at 9.0μ and 8.5μ.

TABLE 1. *Table showing agreement between calculated and observed reflecting power.*

Degrees	*R* obs.	*R* calc.
Fused SiO_2		
5	.57	.57
47.4	.51	.50
67.4	.58	.58
5	.32	.32
48	.34	.35
68	.47	.47
Crystalline SiO_2		
5	.74	.74
27.6	.72	.72
47.6	.80	.79
67.5	.89	.89

TABLE 2. *Table of extinction coefficients and indices of refraction.*

Crystalline SiO_2

λ	$\varkappa$	n
8.13	.32	.40
8.25	1.8	.15
8.38	7.3	.12
8.50	10.	.15
8.63	4.0	.29
8.75	13.	.12
8.83	27.	.05
9.00	27.	.07
9.13	19.	.06
9.25	8.	.35
9.38	2.0	3.0
9.50		3.9
9.75		3.2
10.00		3.6

Fused SiO_2

λ	x	v
8.13	.94	.40
8.25	1.45	.44
8.38	1.65	.52
8.50	1.90	.49
8.63	2.3	.45
8.75	3.4	.36
8.83	4.3	.38
9.00	2.9	.83
9.13	1.8	1.40
9.25	.90	2.5
9.38	.75	3.7
9.50	.50	3.9
9.63	.25	3.5

Curves of the computed values of the index of refraction and extinction coefficient are given through the band of metallic reflection.

It is seen from the curves that the fused and the crystalline quartz have about the same maximal value for their index of refraction (about 4.) at about the same wave length. The maximum extinction coefficient is much greater for the crystalline quartz than for the fused quartz, being 27 for the former and 4 for the latter. Both specimens of quartz show two maxima in the index of refraction, the first absorption band for fused quartz is not resolved.

Data are given in Table 1 illustrating the degree to which the Fresnel metallic reflection formula represents the observed variation of reflecting power with the angle of incidence. The constants of the formula are calculated from the reflecting power at normal incidence (5°) and at (68°). The reflecting powers at some intermediate angles are computed and compared with the measured values. The agreement is within the error of measurement.

The author wishes to express his indebtedness to Professor A. H. Pfund for suggesting the problem and for help in the experimental part of the work.

THE JOHNS HOPKINS UNIVERSITY,
BALTIMORE, MD. APRIL, 1929.

An Introductory Course in Ophthalmic Optics. By Alfred Cowan, M.D. 262 pages. 121 illustrations, many in colors. Second edition. F. A. Davis Company, Philadelphia, Pa. $3.50, net.

This volume, very creditably printed and adequately illustrated, contains simple yet fundamental information regarding reflection and refraction of light at plane and spherical surfaces, ophthalmic lenses, dioptric system of the eye and brief chapters on the anomalies of accommodation and errors of refraction. The book will be found of value to medical students who are specializing in ophthalmology, students in optometry and applied optics as well as to physicists, physiologists and psychologists who desire an elementary text on the subject. The book is the outgrowth of the author's experience in teaching in the Graduate School of Medicine of the University of Pennsylvania. In the introduction we read: "The works of Clay, Glazebrook, Haughton, Ganot, Carhart, Prentice, Southall, Heath, Sheard, Young, Helmholtz, Donders, Landolt, Von Rohr, Tscherning, Howe, Johnson, Zentmayer, Laurance, Jackson, Duane, Henker and others have been freely used, either with or without variation. Care has been taken to include only that part of the subject which concerns ophthalmology." The author has adhered to his purpose and doubtless delivered to those in whom he was particularly interested as rigid a treatise as might be of service to any whose mathematics is limited to algebra, geometry and a little trigonometry. By so doing he has endeavored to give to the reader many facts and principles, with simple mathematical and experimental demonstrations.

CHARLES SHEARD

INSTRUMENT SECTION

EXPERIMENTAL AND THEORETICAL MID-SERIES CHARACTERISTIC IMPEDANCE OF ACOUSTIC WAVE FILTERS

By G. W. Stewart and C. W. Sharp

ABSTRACT

The simplified theory of Stewart and the less approximate theory of Mason are compared with experimental measurements with respect to the mid-series characteristic acoustic impedance of a high-pass, a low-pass and a single-band-pass filters. The comparison is made over a large range of frequencies including a considerable portion of both the attenuation and transmission regions. There is remarkable agreement between theory and experiment, considering the approximations that are made in the theories. For the low-pass filter there seems to be no appreciable advantage of the more accurate theory of Mason. In the other two cases, however, there is a distinct superiority for this theory. For purposes of ascertaining cut-offs, and the characteristic impedance for the low-pass filter, the simpler theory of Stewart is more readily applicable.

The original very simplified form of the theory of acoustic wave filters[1] gave fairly satisfactory values for the experimental cut-off frequencies of low-pass, high-pass and single-band filters. But a more exacting test of the accuracy of a theory of these filters is the agreement of computation and experiment for the characteristic impedance. In this article the characteristic impedance referred to is what is known as the mid-series characteristic impedance, and may be described by reference to Fig. 1.

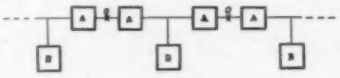


Fig. 1.

Let B represent acoustic side branches attached to the series of acoustic impedances, A, as shown. Let the arrangement be indefinitely repeated, in both directions. The mid-series characteristic impedance is the ratio of the pressure and volume-current at any of the similar points 0. In general all of these quantities are complex. This article reports a comparison of theory and experiment for the value of the characteristic impedance.

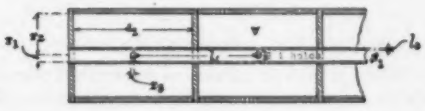
[1] Stewart, Phys. Rev., *20*, pp. 528–551; 1922. Phys. Rev., *25*, pp. 90–98; 1925.

$l_1 = 5.0$ cm
$l_2 = .5$ cm

$r_1 = .483$ cm
$r_2 = .139$ cm

$S_1 = .734$ cm²
$S_2 = .0607$ cm²

High Frequency Pass Filter L-50

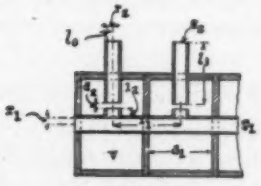


$l_1 = 5.0$ cm
$l_0 = .082$ cm
$d_1 = 4.66$ cm

$r_1 = .243$ cm
$r_2 = 1.71$ cm
$r_3 = .118$ cm

$V = 43.1$ cm³
$S_1 = .186$ cm²

Low Frequency Pass Filter H-3



$l_1 = 2.66$ cm
$l_2 = .2$ cm
$l_3 = 2.268$ cm
$l_0 = .069$ cm

$r_1 = .243$ cm
$r_2 = .243$ cm
$S_1 = .186$ cm²
$S_2 = .186$ cm²

$d_1 = 2.502$ cm
$d_2 = .15$ cm
$V = 22.7$ cm³

Single Band Pass Filter S. B-9

FIG. 2.

The filters, for which the comparison will be made are shown in Fig. 2.

If the impedances A and B are designated by $Z_1/2$ and Z_2 respectively and if the volume current be considered the same throughout any branch, then the characteristic impedance as defined will be

$$K = \frac{Z_1}{2} + \frac{1}{\dfrac{1}{Z_2} + \dfrac{1}{\dfrac{Z_1}{2} + K}}$$

or

$$K = \left[Z_1 Z_2 \left(1 + \frac{Z_1}{4Z_2} \right) \right]^{1/2} \tag{1}$$

Obviously this treatment, demanding the same phase in any branch of the circuit, considers the impedances to be concentrated or "lumped." Eq. (1) contains no other approximations than that the pressure at any junction is the same over the entire junction and the sum of the volume currents at any junction is zero. In Eq. (1) can be used the values of $Z_1/2$ and Z_2 as described in the original theory of the author.[2] K is the symbol used for characteristic impedance when the impedances are regarded as concentrated. Mason[3] has derived the following more accurate expression[4] for the characteristic impedance, assuming that the impedances A are straight tubes:

$$Z_0=\frac{\rho a}{S_1}\sqrt{\frac{1+\frac{i\rho a}{2S_1Z_2}\tan k\frac{l}{2}}{1-\frac{i\rho a}{2S_1Z_2}\cot k\frac{l}{2}}} \tag{2}$$

wherein ρ is the density of the fluid,

S_1 is the area of the straight tubes forming the impedances A of Fig. 1.

a is the velocity of sound in the fluid.

l is the length from a point 0 of Fig. 1 to the next adjacent similar point.

k is $2\pi/$ wave length.

Z_2 is the impedance of the side branch B of Fig. 1.

Z_0 is the characteristic impedance assuming no concentration of impedances A, but of B or Z_2.

To check the theoretical characteristic impedance by experiment, measurements were made using the method developed by Stewart.[5] Denoting the measured impedance, which is complex, by Z, then

$$Z=Z_a+iZ_b \tag{3}$$

Z_a and iZ_b being the real and imaginary parts respectively. This measured impedance is the characteristic impedance of the filter plus the impedance due to the junction of the filter to the measuring apparatus which is

[2] Stewart, *loc. cit.*

[3] Mason, Bell System Technical Journal, *6*, pp. 258–294; 1927. Our Eq. (2) is the equivalent of his (23).

[4] Eq. (2) is obtained from Mason's Eq. (23) by replacing $(P_{\theta\gamma\rho}$ by its equivalent ρa, Z_a/S_2 by Z_2 and ω/c by k. The value is also divided by the area S_1 which gives the characteristic impedance instead of impedance per unit area.

[5] Phys. Rev., *28*, pp. 1038–1047; 1926.

$$\frac{i\rho\omega}{C_0}$$

C_0 being the conductivity of the opening at point of attachment. (C_0 has the value of 4 times the radius of the opening.)

The characteristic impedance is known to be real in the transmitting region and imaginary in the attenuated region. The following relations should therefore hold for the experimental values.

In the transmitting region,

$$\left.\begin{aligned} K=Z_0=Z_a \\ \frac{\rho\omega}{C_0}=Z_b \end{aligned}\right\} \tag{4}$$

In the attenuated region,

$$\left.\begin{aligned} K+\frac{\rho\omega}{C_0}=Z_0+\frac{\rho\omega}{C_0}=Z_b \\ 0=Z_a \end{aligned}\right\} \tag{5}$$

This comparison of measurement with theory applies to both the Mason theory and the more simple and approximate one of Stewart.

In applying equation (1) to the high frequency pass filter L−50 Fig. 2, the following values are used by Stewart:

$$Z_1=\frac{\dfrac{i\rho l_1}{S_1}\omega}{1-\dfrac{\rho l}{S_1}\cdot\dfrac{V_1}{\rho a^2}\omega^2} \tag{6}$$

$$Z_2=\frac{i\rho\omega}{C} \tag{7}$$

l_1 is distance between side branches.

$V_1=l_1\times S_1$.

$$C=\frac{\pi r_2^2}{l_2+(.785+.57)r_2} \tag{8}$$

r_2 = radius of side branch.

l_2 = length of side branch.

The value for C comes from the well known form[6] with the value $\pi r_2/4=.785r_2$ (theoretical) used for the end correction at the junction

[6] Rayleigh, *2*, Art. 307; Eq. 1.

and the value $.57r_2$ (experimental) used for the end correction at the open end of the side branch.

In applying equation (2) the value of Z_2 is[7]

$$Z_2=\frac{i\rho a}{S_2}\tan kl_2' \tag{9}$$

where S_2 is the area of the side branch tube and l_2' its equivalent length. This equivalent length has the value, as before in Eq. (8),

$$l_2'=l_2+(.785+.57)r_2 \tag{10}$$

The value of Z_2, equations (7) and (9), as used in equation (1) and (2) are both approximate and can readily be shown to be equivalent at the low frequencies. In both the cases of Stewart and Mason the length selected for the main line tube is the distance between the centers of the openings of two consecutive side branches. This is evidently an approximation. As has been shown, the corrections applied to the length of the side branch are also approximations.

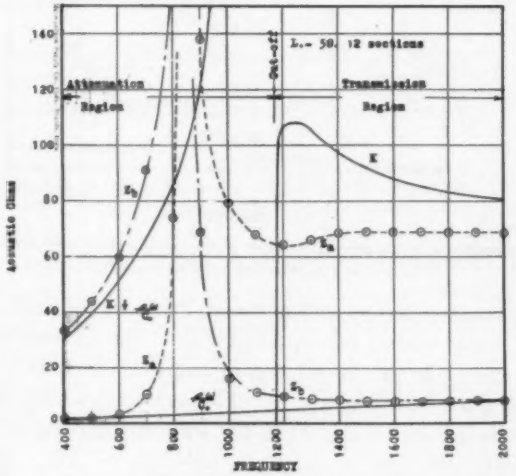


FIG. 3. *Comparison of the measured values of the characteristic impedance of a high pass filter with computations by Stewart's theory.*

Fig. 3 shows the agreement obtained between experiment and the theoretical values found by Eq. (1) for the high frequency pass filter $L-50$. The agreement between $K+\rho\omega/C_0$ and Z_b in the atten-

[7] Mason, Bell System Tech. Jour., *6*, p. 15; 1927

uated region is very poor. The theoretical curve is displaced toward the higher frequencies, the displacement increasing with increased frequency. In the transmitting region the theoretical curve K increases from $-\infty$ and at the higher frequencies gives the best agreement with experimental value, Z_a.

The value of Z_a in the attenuated region approaches zero as closely as could be expected with a filter where there is dissipation. A similar remark may be made of the relation between $\rho\omega/C_0$ and Z_b in the transmitting region.

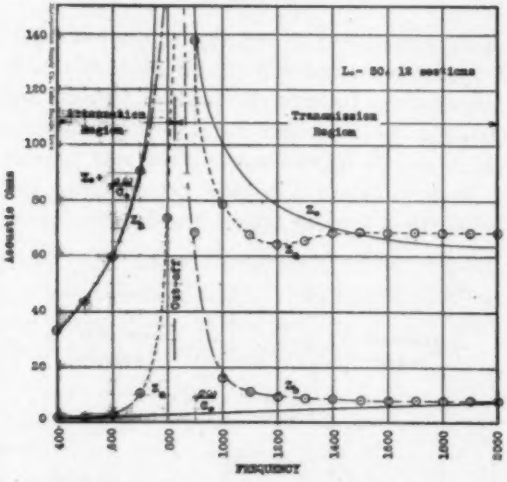


FIG. 4. *Comparison of the measured values of the characteristic impedance of a high pass filter with computations by Mason's theory.*

Fig. 4 gives the agreement obtained between experiment and the theoretical value found by equation (2). The agreement shown is very good except in the cut-off region and even there it is very much better than that shown in Fig. 3. The agreement with theory of Z_a in the attenuated region and Z_b in the transmitting region is the same as that in Fig. 3.

In applying equation (1) to the low frequency pass filter ($H-3$, Fig. 2) the following values are used by Stewart.

$$Z_1=\frac{i\rho l_1\omega}{S_1} \tag{11}$$

$$Z_2=i\left(\frac{\rho\omega}{C}-\frac{\rho a^2}{V_2\omega}\right) \tag{12}$$

V_2 = Volume of side branch.

The side branch in this case is a Helmholtz resonator whose impedance Z_2 is an approximate one. This same value for Z_2 is used in applying equation (2).

The agreement obtained between experimental and theoretical values found by equation (1) is shown by Fig. 5. The agreement is

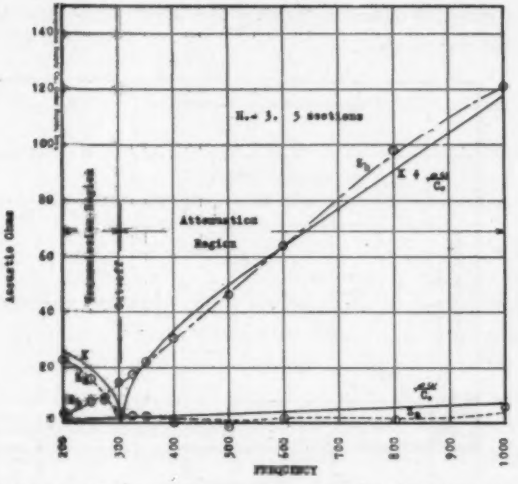


FIG. 5. *Comparison of measured values of the characteristic impedance of a low pass filter with computations by Stewart's theory.*

good for all frequencies. Fig. 6 shows the agreement obtained by means of equation (2). It is practically the same as that shown by Fig. 5. There is no marked superiority shown for either method in the case of low frequency pass filter.

In applying equation (1) to the single band pass filter (*S B*-9, Fig. 2) the values of Z_1 and Z_2 as used by Stewart are[5]

$$Z_1 = \frac{i\rho l_1}{S_1}\omega \tag{13}$$

$$Z_2 = \frac{iM_2\omega(M_2'C_2\omega^2 - 1)}{M_2C_2\omega^2 + M_2'C_2\omega^2 - 1} \tag{14}$$

where $$M_2 = \frac{\rho l_2}{S_2} \tag{15}$$

[5] *Loc. cit.*

$$C_2 = \frac{V_2}{\rho a^2} \tag{16}$$

$$M_2' = \frac{\rho}{C} \tag{17}$$

C = conductivity of the opening into the volume V_2.

The conductivity C used in obtaining the curve in Fig. 8 was taken as that of a circular opening, having the area of the opening into the volume. This value was .42.

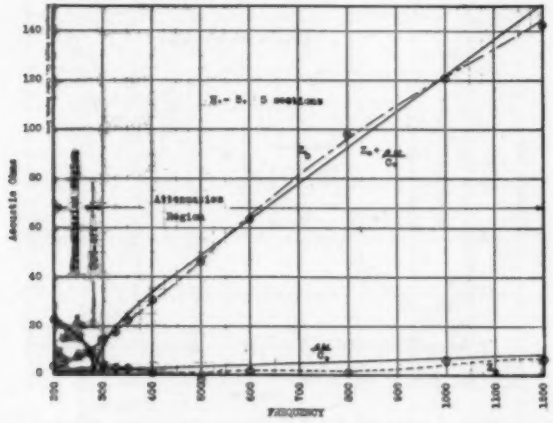


FIG. 6. *Comparison of measured values of the characteristic impedance of a low pass filter with computation by Mason's theory.*

In obtaining the value Z_2, equation (14), the side branch was considered as composed of two parts in parallel joined to the line tube at the same point. As the filter is actually constructed this is not the case and this makes another approximation in the value Z_2 as used in equation (1).

The value for Z_2 used in equation (2) is obtained by extending Mason's equation[3] (with dissipation neglected) to the side branch of the filter.

The equations become on neglecting dissipation,

$$\left.\begin{aligned} p &= p_1 \cos kx - i\dot{X}_1 Z \sin kx \\ \dot{X} &= \dot{X}_1 \cos xk - \frac{ip_1}{Z} \sin kx \end{aligned}\right\} \tag{18}$$

[3] *Loc. cit.* Eq. 15.

wherein

p = excess pressure

$\dot{X} = V$ = volume current

$Z = \frac{Z_{L_2}}{S_1}$ (of Mason)

$k = \alpha_1$,

V and α_1, being the symbols used by Mason.

The side branch to which these equations are applied may be represented as in Fig. 7.

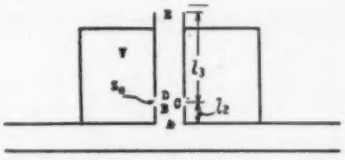


FIG. 7.

The equations are applied to the portion A B and the value for p and $\dot{X}$ at B found. Then the assumptions that the pressure over a junction is constant and that the algebraic sum of the volume displacement is zero, are applied and the value of p and $\dot{X}$ found at the point D. Then the above equations are applied to the portion from D to E and the final expression obtained for the values of p and $\dot{X}$ are:

$$P_E = p_A \cos kl_2 \cos kl_3 - i\dot{X}_A \frac{p_2 a}{S_2} \sin kl_2 \cos kl_3 \qquad (19)$$

$$- i\left(\dot{X}_A - \frac{p_A}{Z_c}\right)\frac{\rho a}{S_2} \cos kl_2 \sin kl_3$$

$$- i\left(\frac{p_A S_2}{\rho a} - \frac{\dot{X}_A \rho a}{S_2 Z_c}\right)\frac{\rho a}{S_2} \sin kl_2 \sin kl_3$$

$$\dot{X}_E = \left(\dot{X}_A - \frac{p_A}{Z_c}\right) \cos kl_2 \cos kl_3 \qquad (20)$$

$$- i\left(\frac{p_A S_2}{\rho a} \frac{\dot{X}_A}{Z_c} \frac{\rho a}{S_2}\right) \sin kl_2 \cos kl_3$$

$$- \frac{ip_A S_2}{\rho a} \cos kl_2 \sin kl_3 - \dot{X}_A \sin kl_2 \sin kl_3.$$

Using the equivalent length of l_3 and assuming that the excess

pressure p_E is zero at the open end, the value of Z_2 which is the ratio of $p_A/\dot{X}_A$ is found to be

$$Z_2=\frac{\frac{i\rho a}{S_2}\left[\sin(kl_2+kl_3)+\frac{i\rho a}{S_2Z_c}\sin kl_2\sin kl_3\right]}{\cos(kl_2+kl_3)+\frac{i\rho a}{S_2Z_c}\cos kl_2\sin kl_3} \tag{21}$$

The actual values used for l_2 and l_3 are $(l_2+.785r_2)$ and $(l_3+.57r_2)$ respectively. The additions being made for the end corrections.

Z_1 is the impedance looking into the side branch chamber and has the value

$$Z_1=i\rho\left(\frac{\omega}{C}-\frac{a^2}{V\omega}\right) \tag{22}$$

where V is the volume of the side branch chamber, and C is the conductivity of the orifice into the volume. The value was here taken to be

$$C=\frac{\pi ab}{b\log_e\left(\frac{4a}{b}\right)+L_0} \tag{23}$$

which is the conductivity for an elliptic channel of length L_0 and semi-axes a and b. This is however only an approximation of the conductivity of the opening used.

As will be noted the values of the conductivity of the opening into the volume of the side branch used in equation (17) and (22) are different. In the first case the conductivity is considered as that of a circular opening and in the second that of an elliptical opening. Both are approximations and there is probably no choice between the two. The difference which the two approximations made in the final result is found to be small.

Fig. 8 shows the agreement with experiment obtained by means of equation (1) and Fig. 9 shows that obtained by means of equation (2). The agreement of (2) is much better than (1) below the first cut-off, and that obtained by equation (1) is better than that by (2) in the transmitting region and above the second cut-off. The agreement, however, is probably as good as can be expected since the values used for the lengths l_1 and l_2, the conductivity of the orifice and the impedance of the Helmholtz resonator are all approximate. Also the filter

used only had three sections which may be another reason for the poor agreement obtained.

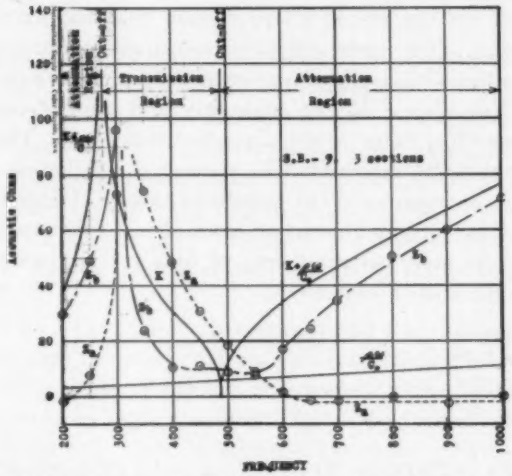


FIG. 8. *Comparison of measured values of the characteristic impedance of a single-band filter with computations by Stewart's theory extended.*

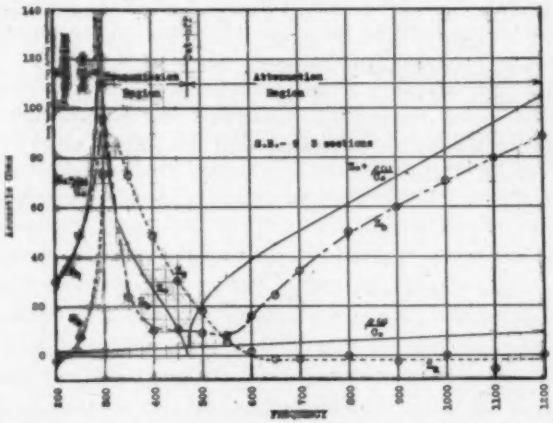


FIG. 9. *Comparison of measured values of the characteristic impedance of a single-band filter with computations by Mason's theory extended.*

In the above comparisons it should be recalled that approximations have necessarily been made in the neglect of dissipation, in the selection

of dimensions and the values of conductivity to be used in the formulas. Moreover, the values obtained by experiment and by computation of the characteristic impedance are compared over a large range of frequencies. On the whole, it can be said that the agreement is gratifyingly good. The more simple theory of Stewart is distinctly inferior to the one of Mason (as here extended) in the computation of characteristic impedance of the high-pass and single-band filters. In the low-pass filter there is not a marked difference. These comparisons are not to be interpreted as of general significance and are informing only as examples. The simplified theory of Stewart seems to be fairly satisfactory for the cut-off frequencies* and is much easier to apply than the more correct theory of Mason. For many uses of acoustic filters the former is adequate.

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* Stewart, *loc. cit.*

Fundamentals of Physics. By A. L. Fitch. xvi+336 pages. 100 figures. 18 portraits. Thomas Y. Crowell Company, New York, $2.50.

The author, using the classical arrangement of subjects, has proceeded on the basis that, "No clear conception of a physical phenomenon is possible until the underlying facts can be expressed mathematically." Occasionally, the reviewer believes, more application of theory to phenomena could well supplant a mathematical derivation. The author had admirably shown recognition throughout of the principle that a physical quantity is not fully expressed until the unit in which it is measured is also stated. Many portraits of great physicists are shown.

A. G. WORTHING

THE DESIGN OF DRAWING CURVES

By P. G. Nutting

Few kinds of special tools are more useful or more widely used by scientists and engineers than the curves required in lining up plotted data and few have been given less attention in the matter of principles of design. Those available come from but a few supply houses catering largely to professional draftsmen. Their design would indicate that they were intended to apply chiefly either to ship ribs or to machine parts rather than to physical, chemical or statistical data. Special sets of "railroad curves" and of ellipses (all of the same eccentricity!) are also listed.

One curve (the 10 inch double logarithmic) I have found more useful for physical and chemical data than all the others together but this is listed in but one size. Many will bear witness to the annoyance of having to line up a set of points essentially in exponential relation to each other when the only curves available are segments of hyberbolas ("ship curves"). To have special sets made up is very expensive. To fall back on a bent stick is both time consuming and annoying.

The makers of these curves are naturally averse to changing their sets of master patterns unless they can do so at a profit. It is clearly for the users to say what they want and insist on having it. If the design can be rationalized and the number kept within reason, I am assured that the makers will gladly consider putting them on the market at a reasonable cost. The fundamental problem is to design a set of curves (not over 70 or 100 at most) in perhaps 4 groups which will fill the needs of at least 90 per cent of the users. I am convinced that this can be done and this paper is presented to open a discussion which it is hoped will end in agreement between scientists (including statisticians), engineers and draftsmen of all kinds on the 70 most useful curves.

Size. Roughly three sizes of each curve are in demand, either 5, 10 and 20 inch, or perhaps better 4, 10 and 25 inch, the two smaller for desk work, the larger for full sheet drawing on a board. The smallest size is most used for machine parts, the middle size for rough scientific data and the largest for data of the highest precision. My own preference is for the 5, 10, 20 set of sizes but there is much to be said for the set of greater range.

Curvature. The range of curvature from one end to the other of a

curve together with the law of variation between extremes are the fundamentals of design. Hence the rational theory of design must deal with the *intrinsic* equations of the curves to be represented—curvature is to be expressed as a function of distance along the curve.

A rule of drafting is to start where the curvature is greatest and proceed outward. Hence the chief selection will be of curves having the proper maximum curvature at the left end. Next comes the selection of those having the proper curvature at the other extreme, in other words the proper range in curvature. The final selection is a curve in which the law of variation in curvature between extremes is best adapted to the data plotted. The three requisites are therefore

1. Maximum curvature.
2. Range in curvature.
3. Law of variation in curvature.

The triple infinity of curves called for are represented by two independent parameters and a series of functions continuously deformable one into another. The practical problem is to select not more than 70 of these which shall differ by just tolerable differences. To the mathematician the problem may appear insoluble because the calculus of variations has not been sufficiently developed to continuously deform one function into any other and because no general transformation from intrinsic to cartesian equations exists.

These mathematical difficulties may perhaps be avoided by cutting our patterns directly from the intrinsic equations and by resorting to series expansions of the actual functions. The first three terms of an infinite series provide the necessary parameters but in a less satisfactory manner than the function itself.

By way of illustration consider the family of second degree curves passing through the origin and symmetrical about the X axis.

$$y^2 = 2rx + ax^2$$

The parameter r is the radius of maximum curvature at the origin. Keeping r constant and increasing a from -1 (circle) to $+\infty$ (coordinate axes) gives a series of ellipses, a parabola ($a=0$) and a series of hyperbolas. Taking $r=1$ inch, I find that the series of 7 curves obtained by making a (a dimensionless number) -0.75, -0.50, -0.25, 0, $+0.4$, $+1.0$ and $+5.0$, constitute a useful set of 10 inch curves. 5 inch and 20 inch sets are simply reduced or enlarged copies of the 10 inch. Curves of very low curvature and curvature gradients (approaching zero) may be cut farther from the origin on the hyperbolas, the parabola and on the ellipses of great eccentricity.

But while such a set of curves satisfies the first two conditions mentioned above it does not satisfy (3) for the law of variation of curvature from one extreme to the other is unchanged. They would be serviceable "ship" curves but not as "railroad" curves for which the first derivative of the curvature with respect to the distance along the curve should be constant. Nor would they be well adapted to lining up the logarithmic and exponential data so commonly met with in physics, chemistry, and statistics.

From the standpoint of intrinsic equations the problem is simple in theory. The direction of the tangent ($\tan\theta = dy/dx$) is expressed as a function of distance s along the curve. Curvature is $c = d\theta/ds$, radius of curvature its reciprocal, $ds/d\theta$. The gamut of useful drawing curves lies between the circle $c = d\theta/ds = \text{constant}$ and the straight line $\theta = \text{constant}$, several laws of variation being used. For example, in a 10 inch drawing curve, the curvature is to decrease from a maximum c_1 at one end to a minimum c_2 at the other. If the variation is linear, $dc/ds = \text{constant}$ and $c = as + b$, where $b = c_1$ and $10a + b = c_2$. If it be not uniform, we may take $c = as^2 + b$ or $c(s+a) = \text{constant}$ (logarithmic spiral), $c\cos\theta = \text{constant}$ (cycloid), $c\sec^2\theta = \text{constant}$ (catenary), $c\tan\theta = \text{constant}$ (tractrix) or any other law of variation.

Such curves would ordinarily be laid out after translating to cartesian form through the transformation

$$dx = ds\ \cos\theta$$
$$dy = ds\ \sin\theta$$

but these lead at once to complex forms many of which are not integrable. The translation into polar coordinates is still more difficult. However it is an easy matter to devise an instrument to plot the simple intrinsic differential equations directly according to any simple law of variation of curvature with length of curve.

My device for drawing intrinsic curves is in the form of a miniature ice boat, hatchet planimeter or toy automobile fitted with tiller steering and a drawing point beneath the rear center. When the steering gear is fixed, such an instrument will draw a circle. In any position the curvature of the curve drawn will be proportional to the distance of the tiller from the central (straight line) position. With the tiller engaging a helical screw thread turning with the rear axle, the curve $c = as + b$ will be drawn. This is the proper form for a railroad curve since it leads to a constant derivative of the (central) acceleration—the condition for maximum comfort and safety. Other simple curves such as the

parabola or cosine may be cut from sheet material and wrapped around the rear axle as a guide to the tiller.

These notes and suggestions are offered for publication in the hope of arousing interest in the rationalization of the design of drawing curves. Possibly a simpler mathematical method of attack has been overlooked. The mechanical device suggested for laying out master curves appears to be as simple and as satisfactory as can be devised. At all events it is time the scientist and statistician were heard from in the effort to secure satisfactory tools.

GEOLOGICAL SURVEY,
WASHINGTON, D. C., MARCH 1929

Infrared Analysis of Molecular Structure. By F. I. G. Rawlins and A. M. Taylor. xv+176 pp. Cambridge University Press, (through Macmillan, New York).

The authors point out "that no book in English exists which deals with the application of infrared spectroscopy to the analysis of molecular structure." It is their purpose, therefore, in this monograph to discuss "the interchange of energy between matter—gaseous, liquid and solid—and infrared radiation."

The first three chapters, dealing respectively with Gases, Liquids and Solids, present an outline of theory and experimental results. The fourth chapter gives an excellent sketch of experimental methods and equipment for infrared work.

The treatment throughout is descriptive, rather than mathematical, the necessary mathematical discussions being included in an Appendix of some 25 pages. Copious references to recent literature are given. Both physicists and chemists will find this book a valuable and up-to-date outline of this important subject.

F. K. RICHTMYER

THE PRODUCTION OF EMISSION FROM OXIDE COATED FILAMENTS: A PROCESS PHENOMENON

By Vernon C. Macnabb

ABSTRACT

The production of oxide filaments of barium and strontium in an emitting condition is investigated from the standpoint of determining the advantages of several apparently different methods of producing this type of cathode as used by several different companies. It is found that all methods amount to the same thing and are different only in degree.

The fundamental underlying action of all methods is that the filament to become emissive must undergo a gaseous bombardment, which presumably causes a breaking down of the higher oxides or compounds, as the carbonate, to the lower oxides or pure metal, and conversely, this breaking down must be caused by or accompanied by a gaseous discharge in order to produce an active filament. The gas most suitable for this action is best obtained from the filament and is best produced from a carbonate that has not been reduced until put in vacuo, and that the gas then liberated and used is probably CO_2.

These conclusions are arrived at by experiments on several different types of filaments containing relatively different amounts of combined or baked-on coating to uncombined coating and in every case results favor those filaments containing most uncombined coating.

Some secondary conclusions are that the baked on coating serves little or no purpose except as a mechanical bond and that the core material on which the coating can be placed may be of a wide variety of material.

If the published literature on the emission of electrons from oxides of the metallic earths be examined up to about 1908, it will be found that they are almost entirely concerned with whether or not the emission is due to the residual gas.[1] In the light of present day knowledge this theory is known to be incorrect, but the observers of that day were very nearly justified in their contentions because of the very important part that this gas does play in the production of emission from an oxide coated filament. And it is the role that this residual gas plays in producing the emission of electrons from the oxides with which this paper will deal.

The telephone repeater tubes as used in telephone and telegraph long distance lines have long been a standard of uniformity and reliability, but have not been available to the public in any large quantities. Recently, oxide coated tubes have been available to the public in any desired quantity in the form of tubes bearing the following type numbers, 112, 112A, 226, 171A, 227, 280, 281, 250.

[1] Soddy, Nature, page 53; Nov. 1907.
A. Wehnelt, Phil. Mag. *10*, 80; 1905.

The filaments of the telephone repeater tubes used in the past have been made by applying alternate coatings of barium and strontium carbonates mixed with a carrier such as paraffin and applied to the filament while hot. This is often called the candle method of coating because the wax is shaped in the form of a candle.[2] After the required number of coatings have been applied, the filament is baked for two hours or less, according to the alloy constituent of the filament core at a temperature of about 1200°C. This baking serves the purpose of producing a closely adherent layer due to chemical combination between the oxides and the core. It is this layer that has always been considered the desirable thing for longevity and high emission, and the basis of this theory is another point which the writer wishes to discuss.

The filament first used was of platinum with a percentage (about 6) of iridium present which helped give the wire considerable mechanical strength and it could withstand long exposures at high temperatures in air. So this wire after coating was baked for two hours. Later it was discovered that platinum with about 5 to 10% nickel was preferable to that containing the iridium and it is this wire that superseded that containing the 6% iridium. The claims made for this wire were that the nickel oxidizes in air and when heated in vacuo reduces to a finely divided state and causes the oxide coating to be more firmly bound up by this finely divided nickel.[3] But the important fact to be noted in this filament is that due to its poorer mechanical properties it cannot be heated in air for more than ten minutes without causing brittleness or poor tensile strength. These two types of filaments and their possible variations have been investigated by the writer and two other widely variant types, the one which will be called the undercoat type and the other the coating used by most of the companies supplying the public with oxide coated tubes.

The variation named undercoat is so named because it consists entirely of underlying alloyed oxides, and is produced by coating the wire with the wax candles and subsequent heatings as outlined above, but to completely remove all uncombined coating by washing with distilled water or a weak ammoniacal solution. This process will leave only the combined or alloyed oxides. The oxide filament in the majority of the tubes available to the public is the other extreme from this filament, containing no combined oxides and is produced by passing

[2] Phenomena in Oxide Coated Filaments Electron Tubes, Arnold, Phys. Rev., *16*, p. 76; 1920.

[3] U. S. Patent No. 1,542,385 to J. E. Harris.

the filament through a water suspension of the carbonates of barium and strontium and baking them on in an atmosphere of carbon dioxide at a temperature at which no chemical reaction occurs between the filament and the carbonates, and as the coating is out of contact with air and in contact with only CO_2, if any reaction does occur, it is reversible and the coating is left in the form of the carbonates. The actual reason for the coating forming a good mechanical bond is not entirely clear, but may be due to the reversible chemical action mentioned above, which changes the finely divided particles of carbonates into a coherent mass and rather sticks it to the filament as a function of its cohesion between particles and subsequent continuity as paint on a polished metal surface, than it does by adhesion to the metal directly. This fact is verified experimentally as the coating of these tubes chip off in large pieces at the point where the filament is bent around the supporting hook and leaves a clean metal surface exposed. An alternate way of producing such a coating is to make a colloidal suspension of the carbonates in a suitable carrier and after applying them to the filament bring it to a temperature at which the colloids are floculated and their carrier driven off and the same filament will result. The temperature at which the colloids will floculate is far below the temperature of decomposition of the carbonates so this coating can be applied and heated in air.

These four varieties of filaments will now be arranged in a sequence depending on the relative amounts of combined to uncombined coating. The undercoat type starts the list as having no uncombined coating whatsoever, followed by the filament containing iridium, which, due to its two hour baking period contains a considerable quantity of undercoat but has some uncombined coating. Next the filament containing nickel was baked for only a short time and rather depended on the reduction of its nickel oxide after being lighted in a vacuum for its mechanical bond than on the formation of an undercoat while baking in air. At any rate, owing to its shorter baking period this filament has more uncombined oxides than either of the two previous types, and lastly, the entirely uncombined coating.

The writer's experiments were made on tubes using a standard sized plate and grid as used in the 112 tubes and the filaments so dimensioned that their normal operating current and voltage was obtained with 0.250 amperes at 5 volts and required about a 4 to 4-1/2 inch length of filament, depending on the resistivities of the different alloy filaments used, and on the different heat radiation factors of the various filaments

due to their different surfaces. The uncombined filament remains a pure white, while the undercoat is quite black and the other filaments have different color schemes containing black, brown, green and gray. The blacker the filament the better radiator of the power supplying heat to the filament, so much so that the undercoat filament on the same core as the overcoat filament would require from 20 to 30% more power to maintain it at the same temperature. All these tubes were exhausted on the same all glass manifold, the tubes being sealed to the manifold, which in turn was sealed to a Pyrex glass condensation pump through a graded seal and liquid air trap. The degree of vacuum was measured in each case by a Buckley ionization manometer sealed directly to the manifold and the vacuum obtained was of the order of 10^{-4} to 10^{-5} mm of Hg, but was the same for all tubes. The tubes were baked out at a temperature of 450°C for one half an hour. A piece of magnesium was welded to the plate in each tube and flashed during the bombardment process.

All tubes were treated out by internal bombardment, i. e. the filaments were lighted and voltage applied between filament and plate and grid connected together. And it was at this point that the first great difference in filaments was noted. Remembering that these tubes all had a five volt filament, when the uncombined coating was lighted at six volts and a voltage applied to the grid and plate, the blue haze of ionization immediately appeared and the space current could be increased to bring the grid and plate to a yellow heat to liberate the absorbed gases. If this filament had not been lighted on the pump prior to the start of bombarding, it would be reasonable to assume that the carbonates breaking down would allow the liberated CO_2 to act as a gaseous carrier, but even if the filaments had previously been lighted on the pump and the carbonates more or less reduced by applying 8 to 10 volts to the filament, the ionization would start immediately at 6 volts. In fact if the filament had not been lighted previously in vacuo it was advisable to allow the liberated CO_2 to be partially drawn off before the anode voltage was applied, as the discharge in the presence of the CO_2 would be so intense as to knock off pieces of the coating.

Next the platinum nickel filament would require anywhere from one to five minutes to start ionizing at six volts and in order to accelerate the removal of the tubes from the pump and to insure quick starting of the ionization it was necessary to light them at 7 to 8 volts.

The platinum iridium or two hour baked filament would hardly start at six volts and required 10 to 11 volts to start and lastly the undercoat

filament was difficult to start at all, because in order to secure enough emission or gas to start any ionization in the tube the filament had to be taken to a temperature dangerously near burnout.

These relative results point out the necessity of having some uncombined coating to start the ionization and subsequent treating out of the tube. This effect of ionization in the activation of the filament is very interesting and very suggestive. At the start, the space current that flows seems to be entirely conducted by gas, which is ionized by a small emission of electrons from the filament. So the requirement for the start of activation is some emission and some gas, the emission starting the ionization and the ionized gas taking up the job and carrying it to a conclusion. As the occluded gas is liberated from the plate and grid a haze fills the bulb and finally as the pump draws it off a faint glow only is visible in the spaces between the elements, but the plate and grid are still as hot or hotter than when the glow was present, and therefore the space current must necessarily be carried to a great extent by electronic emission. As the filament is at the same or even lower temperature than at the start (as it is advisable to decrease the filament voltage as the gas clears) it shows that the filament is not in a condition to emit as soon as a vacuum is produced, but must undergo an activating process which the internal bombardment furnishes. The idea that the internal bombardment serves the purpose only of degassing the elements seems incorrect as regards oxide coated filaments. Further proof of this activation process is that at the start, when the blue glow discharge first occurs, if the filament is turned down so that the little emission it has is stopped, the gaseous discharge, which was started by the electron emission will persist and concentrate or arc at one spot on the filament, as any gaseous discharge between points, and burn the filament out at this point. However, as the bombarding proceeds, the filament can be safely turned down without danger of burning out the filament.

These statements of the action of the filament during the time of bombardment hold for all the filaments mentioned and it is only in their starting that the difference is noted, although the undercoat filament cannot be reduced to the same voltage as uncombined coating immediately after the ionization has started.

A trick that will allow an undercoat filament to start ionizing at a low voltage is to admit some gas from an extraneous source. One way is to light the filament of a tube next to it and the gases occluded in that filament flowing over to the one on which voltage has been applied for

a few minutes will allow the latter to start ionizing. Another is to lower the liquid air bottle so that some gas is liberated from the trap. This would indicate that the gas liberated from the uncombined coating is the reason for their much greater readiness to start ionizing. However, after the tubes are completed, the total emission from the filaments decreases in the same order as their difficulty in starting increases, and this greater emissivity of the uncombined coating when taken off the pumps would seem to be intimately tied up with the effectiveness of the treating out process.

As the reading of total emission of an oxide coated filament by placing a high voltage on the grid and plate will harm the filament due to the large current passing, the activity was judged by reading the plate current that flowed with 90 volts on the plate and +15 volts on the grid. It is obvious that filaments of low activity will be at saturation or approaching it, whereas filaments of high activity will still have an abundance of available electrons, and will not indicate a limiting value. The following values are an approximate average of at least one hundred tubes, all exhausted, as mentioned before, under the same conditions, in fact, tubes of different kinds were often taken off side by side and had the same pumping and bombardment.

	$Eg = +15$v Ip at $Ep = +90$v $Ea =$ 5 v $Ia =$ 0.250 a
Uncombined coating	50 ma
Candle coating on Pl Ni	35 ma
Candle coating on Pl Ir	25 ma
Undercoat or combined coating	10 ma

In order to eliminate any doubt as to the material used in coating, a number of tubes were made with the candles, half being of the type baked for 10 minutes at about 1200° C on a platinum nickel core, the other being the same core and candles but no baking and the temperature not raised to a value that would break down the carbonates, or cause any alloying with the core. This latter half gave the same results as tubes made with the carbonates baked on in CO_2 or made with the carbonates in colloidal form. Apparently it is not critical how the coating is applied as long as it is processed correctly.

Another interesting thing about these filaments is the fact that the only filament that can be expediently activated or brought into an

emissive condition without internal bombarding is the uncombined coating. A tube containing this type of coating can be taken off a pumping system in the following manner. As soon as a moderate vacuum has been obtained the tubes are lighted at 8/5ths of their normal voltage for a minute and are then pumped to as high a vacuum as available, which for an oil pump may be from .001 to .005 mm of Hg or for a mercury condensation pump from 0.0001 to 0.00001 mm of Hg. It is the writer's opinion that for this method of activating the tubes it is useless to attain the higher vacuums as the vacuum is partly lost during the activating process. The elements of the tubes are now heated to a white heat by a high frequency induction coil or bombarder until any glow present clears out and the magnesium flashes and deposits on the glass, left to continue pumping for a minute or so longer for the liberated gas to be drawn off and then tipped off. A variation of this method is to have the filament lighted while the plate and grid are being externally bombarded, as this simulates to a slight degree internal bombardment as the high frequency currents flow by capacity effect to the filament and give the same effect as an alternating voltage applied between the filament and the inside surface of the glass. This latter variation may be superior to the other method of not lighting the filament while bombarding but the difference is small. How far the reduction of the carbonates or activation of the filaments are carried is not certain but at least the filament has little or no emission if tested without further treatment, whereas a tube taken off by internal bombardment has attained its maximum activity at the conclusion of the treating out.

A tube exhausted by this method and containing the uncombined coating can be brought into an emissive state by one of several activating schedules. Probably the simplest is to place 110 volts dc between filament and plate with a 25 watt lamp in series and to increase the filament voltage to as high a value as necessary to start a glow discharge. If the lamp were not present to limit the space current the heavy discharge would burn out the filament. This glow will persist for a few seconds and suddenly clear up and the filament will then be found in an active condition. The objection to this method is that it is rather critical to the residual gas available, for if the gas is too little the filament will be insufficiently activated and if the gas is too much it may not clear up. In the latter case the tube can be rebombarded and in the former a tube can often be activated by taking the filament almost to its melting point for a few seconds, this apparently allowing

such gas to be liberated that would not be driven off at the lower temperatures.

A better method is to apply a voltage between filament and grid with a 25 watt lamp in series and the filament at 50% over-voltage and the discharge current quickly increases to a value limited by the lamp. During this period the grid gets quite hot and the filament has a period of activation analogous to that received by internal bombardment. Next a space current is allowed to flow to both grid and plate and its value is limited by decreasing the temperature of the filament so that neither grid nor plate get hot and during this period the gas is largely adsorbed on the magnesium, glass and elements. The gas here again plays the all important part in bringing the filament into an active condition and none of the other three types of filament can be made to give any reasonable emission by such a process apparently because of the lack of the proper gas.

It is interesting to note that if the uncombined coating is heated to a too high temperature during exhaust it will be very difficult or impossible to make it emit, probably because at higher temperatures its mechanically occluded or chemically combined gas, normally available for activating, is driven off.

Tubes made by this external bombardment method usually have a shorter life than those taken off by internal bombardment even though taken off high vac pumps, as the vacuum is probably spoiled during activation. However, these tubes can often be reactivated after failing in emission by either of the methods noted above, particularly by the use of very high voltage on the filament, and in this respect they simulate thoriated tungsten and further strengthen the theory of their activation being due to a process phenomenon. *(note footnote 4), The same tubes taken off a high vac pump by internal bombardment will last several times as long. Also, the filament material for the uncombined coating is not very important, cores of platinum nickel, platinum iridium, pure nickel and nickel chromium alloys having been used with equal success, and no doubt tungsten, molybdenum etc. could be used. An advantage of this fact can be taken in picking a material that will have such a resistivity as to give a filament length required for the tube in mind.

An attempt to theorize on the action that goes on during this activation would be more or less guess work but it has been suggested that heating alone would form a crystalline structure and the reduction

of carbonates or higher oxides[4] to the lower oxide or pure metal and still retain them in an amorphous condition can only be obtained by a gaseous discharge. It can be assumed that any of the four filaments mentioned can never have lost all or can at least have picked up some CO_2 and formed carbonates from the time of its coating to the time of its exhaustion and so emission from any filament can be attributed to processing and breakdown due to processing, its activity being a function of the available gas for processing.

Everything seems to indicate that CO_2 is the necessary gas to have available for this activation as it is the gas present in oxide filaments. The shortening of life of tubes taken off by external bombardment is probably caused not by the CO_2 left in the tubes but by other gases as water vapor, oxygen etc liberated from the grid and glass during activating, whereas these gases are drawn off by the pump during internal bombardment.

The conclusions to be drawn from the above experiments and results are as follows:-

1. Gas, probably CO_2 only and a gas discharge, i. e. positive ion bombardment are necessary to produce the oxides of barium and strontium in an emissive state and that it is the processing that is the important factor in obtaining emission from an oxide coated filament, and the fact that the desired elements are present in the filament is no criterion for electron emission.

2. That the best source of the necessary gas to be used in processing is in the filament itself and can best be obtained by leaving on the filament a large percentage of uncombined oxides as the gas liberated from the filament is probably CO_2 or of some nature that is not poisonous to the filament.

3. That the combined layer of the oxides with the core comprise little or no part of the active part of the filament and only serve as a mechanical bond.

4. That the core material, if it has no chemical reaction with the coating, is not critical in aiding or preventing electron emission.

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[4] This conclusion and two previously mentioned observations, namely, certain gases increasing activity and high temperature activating the filament is pointed out in a paper by Koller, in which he presents evidence to show that the emission is due to the pure metal and not the oxides. Electron Emission from Oxide Coated Filaments, Physical Review, *25*, pp. 671-676; May, 1925.

ON THE EFFICIENT UTILIZATION OF SOLAR ENERGY

By R. H. Goddard

For many years, ideas relative to the construction and operation of solar radiation engines have been advanced, and practical devices based upon these ideas have been constructed. In all the engines, however, there have been heat losses of sufficient magnitude to reduce the efficiency considerably below that of well-designed heat engines of other types.

The question may well be raised as to whether or not a solar engine is necessarily an inefficient device, or has capabilities of high efficiency. If the latter is true, the further question may be asked as to what design of solar engine will meet the necessary requirements.

The most logical procedure is to list the conditions to be satisfied by an ideal solar engine, and then to see how nearly each condition may be realized in actual practice. The ideal engine should meet the following requirements, which incidentally might well be used as criteria for defining in a practical way the ideal heat engine of any type.

1. All the energy received should be absorbed, the upper limit of temperature of the working substance being high, and the exhaust temperature of the working substance being low. 2. There should be no loss of the absorbed heat, either by conduction, convection, or radiation. 3. There should be no fluid, or other mechanical resistance. 4. The engine should be of simple and light construction.

Let us examine the design of solar engine illustrated in Figs. 1 and 2, and see how nearly it fulfills these requirements. Solar radiation, from an optical system which brings the rays, R, to a small focus, S, Fig. 1, enters through the hemispherical quartz window W. The liquid to be vaporized, L_1, enters, under pressure produced by any suitable means, through a pipe P_1, and passes through the space between a short chamber C and an outer casing K, bolted to the window W with a packing-ring, D, inserted between. Thence it enters the chamber C through the open end, which faces the window W, the inner surface of C being reflecting.

Another liquid L_2, having different optical properties, is introduced under pressure, through the pipe P_2, to a hollow ring O, Fig. 1, forming

the open end of the chamber C, this ring having fine holes for the purpose of projecting many small drops into the focus, S. The mixture of liquids becomes opaque at S, owing to the repeated reflections between the small droplets of the liquid L_2, in a well understood manner.

The absorption of energy raises the temperature at S sufficiently to vaporize and superheat either the main liquid L_1, or both liquids, and the vapor thereby produced passes through the constriction or throat T, into the expansion nozzle N, from which it issues at a very high speed, and is used in a turbine, preferably provided with a con-

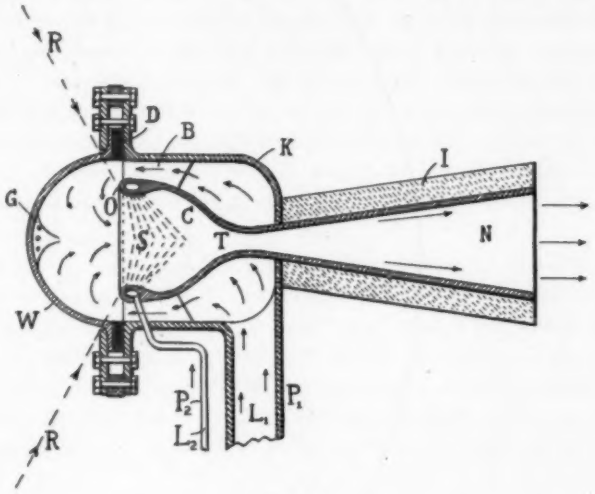

FIG. 1.

denser, to lower the exhaust temperature. From this condenser the two liquids may be separated by any well-known means, as by gravity or centifugal force. Stream-line flow of the liquid L_1 is aided at the window W by a hollow cone, G, of thin quartz, having small holes as shown in Fig. 1, these holes permitting a slow flow of the liquid L_1 through the cone, but not interfering with the main stream-line flow of L_1 along the outside surface of the cone. The chamber C is supported by several thin webs, B, extending radially between C and K. The nozzle may be covered with a heat-insulator, I, and also jacketed, in part, by the casing K.

The mirror system should provide a small solar image at S, and may consist of a single parabolic mirror, M, of short focus, Fig. 2,

either used alone, or used to concentrate the rays from the solar image of a much larger parabolic mirror, of longer focal length. If desired, the mirror, *M*, of Fig. 2, could be replaced by a quartz lens.

Regarding the first condition to be satisfied by the ideal solar engine, namely the complete absorption and efficient thermodynamic utilization of the incident energy, it will be observed that in the solar engine described above, the radiations strike the quartz window substantially perpendicularly to the surface, and hence reflection is reduced

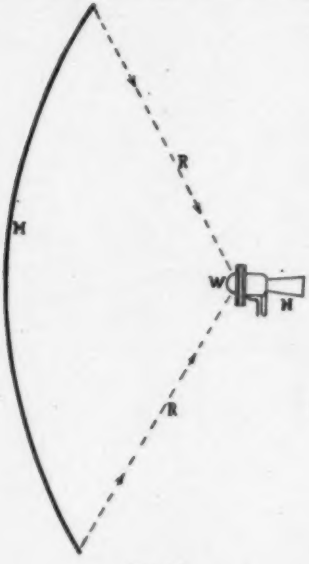

FIG. 2.

to a minimum. Further, all the energy passing through the window *W* is absorbed at the focus *S*, where the two liquids mix.

Inasmuch as the heat is received by the liquids directly, and not through any intermediate metal plate or wall, the temperature of the vapor may be as high as desired. It might be supposed that a thin porous black disk, or grid, with holes in the direction of flow, placed over the opening *O*, of the chamber *C*, might serve as an efficient vaporizer of the liquid L_1, as it passed through this heated partition. Even in this case, however, heat would be communicated from the grid to the liquid by conduction through the vapor in contact with the grid surface, and there would not be the intimate contact that is possible within the mix-

ture of the two liquids. A high degree of expansion and low exhaust temperature is made possible by the use of the expansion nozzle, turbine, and condenser. The type of solar engine described, therefore, satisfies very closely the first ideal condition, in that most of the incident energy is absorbed, producing a high temperature of the working substance, there being also a low exhaust temperature.

In considering the second condition, that there be no loss of the heat absorbed at S, it will be well to examine the conduction, convection, and radiation separately. Conduction rearward, toward the mirror M, is not possible, as the liquid L_1 is entering the chamber C from this end. Some conduction through the wall of the chamber C takes place, but this merely serves to heat the incoming liquid L_1, and hence is not lost. A very important point in this connection is the short distance of travel of the intensely heated vapor from the focus S to the constriction T. This avoids the heat loss which has existed in all solar engines hitherto made involving the use of pipes for the transportation of the heated fluid.

Convection is eliminated by the rapidity of flow of the liquid L_1. Radiation of the heat from S is prevented in the forward direction by the reflecting inner surface of the chamber C, and is prevented in the rearward direction, toward the mirror M, by using for L_1 an athermanous liquid, as, for example, water. Such heat as is absorbed, however, enters the chamber C with the stream of liquid. There is, therefore, a minimum of possible heat loss from the high-temperature region, S.

As to the third condition to be fulfilled by the ideal solar engine, there is a minimum of fluid resistance for two reasons, first, the streamline flow, not only of the liquid L_1, but also of the vapor; and, secondly, the short distance of travel of both the liquids and vapor. The work necessary to pump the liquids L_1 and L_2 is small in proportion to the work delivered by the engine, for the reason that the volumes of both liquids are small compared with the volume of the vapor.

Finally, the fourth condition for the ideal solar engine is met for the reason that, no matter what temperatures and pressures are used, the energy is absorbed within a very small volume, and is transformed into mechanical energy in the immediate neighborhood of this volume. Thus, not only is the volume and surface of what might be considered as the boiler of the engine reduced to a minimum, but the length of the engine is also small. Further, the construction is simple, and all

the parts may consist of light materials, inasmuch as no part withstands a combined high temperature and high pressure.

As to details of materials and construction, the liquid L_1 may be water, and the liquid L_2, having different optical properties and used in a small amount, may be mercury. The water may advantageously be replaced by a liquid having a higher boiling point, a high temperature of dissociation, and also for some purposes a lower freezing point, such as isobutyl alcohol or diethylaniline. Further, one of the liquids may have fine black solid particles, as graphite, held in suspension. The essential features of the solar engine herein described are set forth in U. S. Patent No. 1,700,675, issued to the writer January 29, 1929, entitled "Vaporizer for Use with Solar Energy."

In conclusion it may be said that, instead of being a necessarily inefficient heat engine, the properly designed solar engine may rival in efficiency and smallness of bulk any other type of heat engine that can be imagined. This results from the easy utilization of very high temperatures, together with low heat and frictional losses. Expressed in another way, the properly designed solar engine is capable of handling enormously concentrated energy, such concentration of energy making possible maximum heat absorption, together with minimum heat loss, and minimum size. An interesting feature of the solar engine herein described is an extreme of lightness, for a given power, which no other type of heat engine can approach. This results from the small size, possibility of using light materials, and absence of weight of fuel.

CLARK UNIVERSITY,
WORCESTER, MASS.,
APRIL, 1929.

MAGNETIC TESTING FURNACE FOR TOROIDAL CORES

By G. A. Kelsall

When making magnetic tests at high temperatures trouble is often experienced in maintaining the insulation between turns of the magnetizing and exploring windings and between the windings and the test sample.

A magnetic testing furnace for toroidal specimens designed to eliminate these difficulties is shown in Figs. 1 and 2. The heating compartment consists of an annular trough shown at the right in Fig. 1 and a cover which is shown on the left in the same figure. These two parts are machined from lavite. Two heaters non-inductively wound and imbedded in alundum cement are used. One is in the bottom of the trough with its terminals projecting through to the outside as shown at the left. The other heater is in the cover with the terminals projecting through the top.

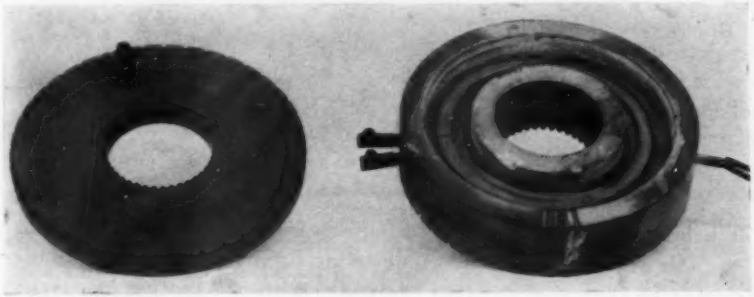

Fig. 1. *Heating compartment.*

This furnace is designed for the testing of rings with a maximum outside diameter of 5″ and a minimum inside diameter of 3-1/4″. Either solid or laminated rings may be used for test specimens. The specimen for test is placed in the bottom of the trough. In order to aid in maintaining uniformity of temperature throughout the ring, a wide copper ring 1/16″ thick is placed between the heater and the test sample. A thermocouple is welded to the outside of the ring specimen and is brought out through the wall of the trough. In Fig. 1 a ring made by winding spirally .006″ by 1/8″ tape of magnetic material is shown in position with the thermocouple welded to the outside turn and brought out at the right.

In assembling the apparatus for test the cover is placed in position and the magnetizing winding wound around the furnace, the turns being evenly spaced by means of notches. The furnace is now placed between two transite discs as shown in Fig. 2. These discs are also provided with notches which determine the spacing of the turns of the exploring winding. With the furnace wound for test as in Fig. 2 there are 40 turns in the magnetizing winding and 90 turns in the exploring winding.

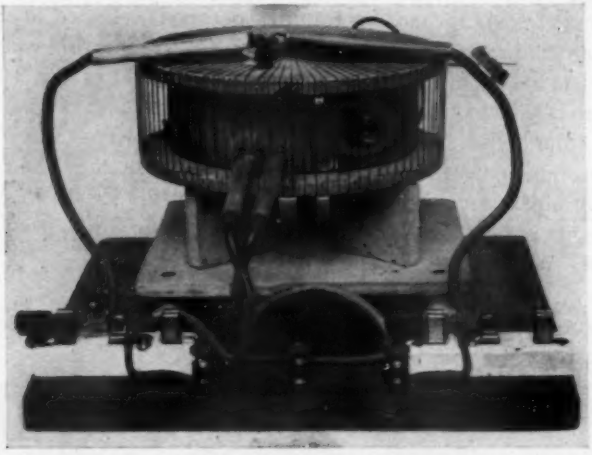

FIG. 2. *Apparatus assembled for test.*

When making tests the heater windings are connected in series with a variable resistance to either a dc or ac supply. The heater windings may be connected in series or parallel with one another by means of the switches shown. The thermocouple is connected to a suitable meter for recording temperatures. The magnetizing winding is connected to a dc source and the exploring winding to a ballistic galvanometer in the usual manner.

By means of this furnace, magnetic properties may be readily determined under a variety of conditions. The test sample may be passed through a definite temperature cycle and the variation in magnetization for a constant magnetizing force determined, or the temperature may be held constant while measurements are made for the B-H curve or for a hysteresis loop. Also this furnace has been found convenient in taking instantaneous hysteresis loops in connection with a cathode ray oscillograph.*

* A Braun Tube Hysteresigraph. J. B. Johnson, Bell System Technical Journal, April, 1929.

Tests have been made at temperatures as high as 850°C and no difficulty has been experienced in maintaining proper insulation between the different parts.

BELL TELEPHONE LABORATORIES,
NEW YORK, N. Y., FEBRUARY 27, 1929.

Handbuch Der Physik, under the general editorship of H. Geiger and Karl Scheel. Vol. XX: Licht als Wellenbewegung. Edited by Dr. H. Konen (Bonn), with the collaboration of L. Grebe (Bonn), K. F. Herzfeld, (Baltimore), W. König (Giessen), A. Landé (Tübingen), H. Ley (Münster), R. Mecke (Bonn), G. Szivessy (Münster), K. L. Wolf (Königsberg), and G. Wolfsohn (Berlin-Dahlem). xiv+967 pp. Julius Springer, Berlin (23-24 Linkstrasse). Paper, M 86; cloth, M 89.

Merely to leaf over the pages of this exhaustive treatise is sufficient to impress one with the impossibility of giving, in a review, an adequate description of its contents. The book of course follows the general plan of the other volumes in this well-known series. Each section is written by a specialist, and the several parts then carefully assembled under the direction of an editor.

The book is divided into three main sections: A, The Nature of Light; B, The Wave Theory; and C, The Optics of Crystals. The five chapters of part A (140 pages) deal, respectively, with: I, Interference experiments, classical and modern, including elementary theory (Grebe); II, Diffraction (Grebe); III, Atmospheric diffraction phenomena (Mecke); IV, Polarization (Szivessy); Laws of black-body radiation (Grebe).

Part B (594 pages) contains five chapters, viz: VI, Electromagnetic theory of light (König); VII, Rigorous theory of interference and diffraction (Wolfsohn); VIII, Optics, mechanics and wave mechanics (Landé); IX, Optics and thermodynamics (Landé); X, Absorption and dispersion (Wolf and Herzfeld).

Part C (320 pages) contains one long chapter, XI, on the optics of crystals by Szivessy, and a short chapter on Polarization and chemical constitution by Ley.

Throughout the book theory predominates. While, of course, experimental results play an important part in the development of the various chapters, and there are numerous references to original articles, yet the work may quite correctly be characterized as a compendium of theory, classical and modern, relating to light as a wave phenomena. As such, it is a most valuable contribution to the literature of optics, not only because of the exhaustive treatment of the various phases of the subject but also because of the careful correlation of the older and the newer concepts.

F. K. RICHTMYER

AN IMPROVED CONSTANT CURRENT REGULATOR

By Lewis G. Longsworth* and Duncan A. MacInnes

A constant current regulator for use in connection with the determination of transference numbers of ions of electrolytes by the moving boundary method has been described by MacInnes, Cowperthwaite, and Blanchard.[1] The moving boundary involved is at the junction of two solutions of electrolytes having a common ion. The leading solution contains ions having higher mobilities than those of the following solution. Such a boundary can, for instance, be formed between solutions of potassium chloride and lithium chloride. When current is passed the boundary moves and the resistance of the system steadily increases. The constant current regulator described in the paper referred to was limited to adjustments of the current for variations in only one direction, which met the requirements of the method. In constructing a new apparatus it was decided to remove this limitation in order to adapt the apparatus for general use. It was found that a simple additional device, to be described below, was sufficient to accomplish this result.

The apparatus is outlined diagrammatically in Fig. 1. The cell, through which the constant current is to pass, is connected to the leads at the point C. Current for the cell is furnished by the battery of storage cells $A-B$. Part of the cells are shunted by the resistance R which is provided with a screw adjustment for the contact T. This adjustable resistance may also be placed in series with the battery. The current through the cell is measured by determining the drop of potential across the constant resistance R' by means of the potentiometer P. The galvanometer G used in connection with the potentiometer is of the portable type, indicating with a needle. In our work this needle is provided with a vane V of aluminum foil. The light from the filament of the 6 cp lamp S is focussed on this vane by the lens L. If not shaded by the vane the light passes to the photoelectric cell K. In our recent work this cell is of the General Electric PJ-15 type. When the photoelectric cell is made conducting by illumination a potential is placed on the grid of the three element tube O, from the battery D, thus stopping the current, between the filament and plate,

* National Research Fellow.

[1] MacInnes, Cowperthwaite, and Blanchard, J. Am. Chem. Soc., *48*, p. 1909; 1926.

which operates the sensitive relay N.[2] This relay in turn operates the relay J.

Up to this point the apparatus is, except for minor changes, the same as the one previously described. In order, however, to make corrections for both positive and negative deviations from the desired current strength the following scheme was adopted. A small motor M continuously turns a circular Bakelite disk F. A shaft holding the grooved pully P_1 and the rubber-tired pulleys P_2 and P_3 is pivoted

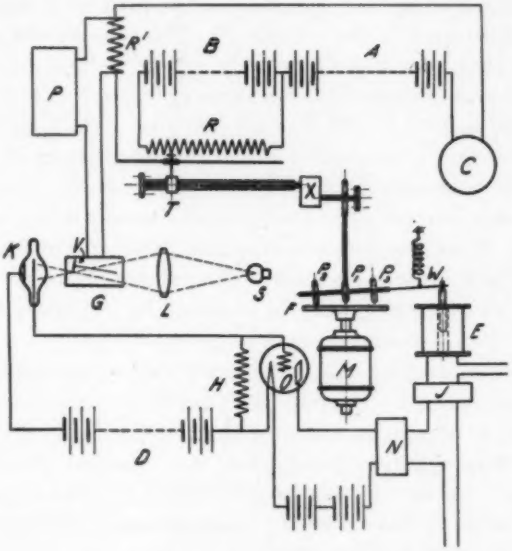

Fig. 1. Diagram of constant current regulator.

with bearings above and below the pulley P_1 so that the shaft can swing around an axis at right angles to the axis of the disk F, and to the shaft itself. The pulley P_1 is connected by a light belt to the reducing gear X, which in turn operates the screw adjustment to the contact point T on the rheostat R. The shaft containing the pulleys P_1, P_2, and P_3 is normally held by a spring W so that pulley P_2 is in contact with the revolving disk F, thus driving the contact point T in a forward direction. If, however, the electromagnet E receives current through the operation of the relay J, pulley P_3 is brought in contact with F and the motion of the contact T is immediately reversed. The

[2] Type Western Electric B 108 Telephone Relay.

effect of this arrangement is as follows. If the potential across the resistance R' drops due to an increase of the resistance of the cell at C (or to running down of the batteries $A-B$) the vane V of the galvanometer swings so as to illuminate the photoelectric cell, thus stopping the current through the three electrode tube, the relays, and the magnet E. This permits a forward movement of the point T, which soon makes very slightly more than the required correction, whereupon the reverse movement of the vane V causes, through the operation of the relay system, the operation of the magnet E and the reversal of the adjustment of the contact T. The vane on the galvanometer needle is thus kept hovering closely around its zero position whether or not there are changes in the resistance of the cell at C or of the potentials of the battery $A-B$. The sensitiveness of the apparatus is shown by the fact that a reversal of the adjustment occurs if the potential across the terminals of R' differs by 0.1 millivolt from the reading of the potentiometer. The total potential across R' was usually about 1.5 volts. Thus a variation of less than 0.01 per cent from the correct potential will cause a reversal of the adjusting system. Still greater precision of adjustment may be obtained by increasing the resistance R', or by the use of a more sensitive galvanometer.

The motor, magnet, and pulleys are shown diagrammatically on a larger scale in Fig. 2. The pulleys P_2 and P_3 are constructed so as to be adjustable as to position along the shaft, so that if, for instance, greater positive than negative adjustments are expected the corresponding pulley can be placed further from the pivot U. The magnet E is constructed so as to have a nearly complete magnetic circuit and gives ample pull on 60 milliamperes.

In order to test the efficacy of this apparatus measurements were made with a silver coulometer under two different conditions. In the first series of experiments the current was derived from a six-volt storage cell, with the apparatus compensating for such changes of resistance and emf as normally occur in the cell and coulometer. In the second series an adjustable resistance which could be gradually increased or decreased was included in the circuit.

The silver coulometer used was of the usual Richards type consisting of a platinum dish of 75 cc capacity containing 15% silver nitrate solution, in which was immersed a silver anode surrounded by an alundum porous cup. During the measurements the coulometer was kept in a large glass container. Most of the suggestions of the

Bureau of Standards for accurate work with this instrument were followed. The silver nitrate solutions were prepared from the "*C. P.*" salt with careful exclusion of organic matter. Weighings were carried out using weights which had been compared with a set calibrated by the Bureau of Standards. The silver deposits obtained consisted of uniformly distributed small crystals with no evidence of striations, the latter being, as is well known, evidence of contamination.

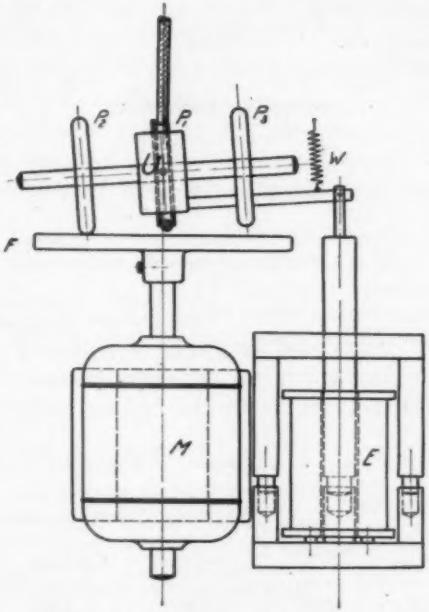

Fig. 2 Mechanism for reversal of adjustment.

In the first series the connections were made as in Fig. 3 (a). The coulometer C was connected in series with the carefully calibrated oil immersed resistance R', of about 9 ohms (the terminals of which were connected to the potentiometer P of Fig. 1). In the same circuit was also a storage cell of 6 volts, and the resistance R_1 of about 40 ohms which was shunted by the variable resistance R of 1760 ohms. The resistance R was automatically adjusted as described above. The results of this series of determinations are given in Table 1. During these runs the motion of the edge of the vane V of the galvanometer of Fig. 1 was about 0.2 millimeter. Since the galvanometer deflected

1 mm by a deviation of 0.5 millivolt from adjustment and the total voltage reading of the potentiometer was 1.5 volts the current was always within 0.01% of the value given in the table. The reversals of adjustment took place about 35 times per minute. The number of

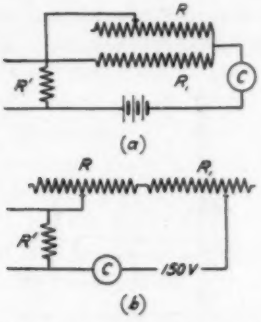

Fig. 3. Connections of coulometer circuits.

reversals was increased from about 10 per minute by placing a tension (by means of a cord, pulley, and weight) on the contact T, thus keeping the bearing surface on one edge of the screw thread. This avoided adjusting for the play between the threads on each reversal.

Table 1. Results of coulometer experiments. Small changes in resistance.

Experiment	Current (amperes)	Time (seconds)	Weight of silver deposit, grams		Per cent error
			Observed	Calculated	
1	0.12842	10800	1.5506	1.5506	0.00
2	0.13794	18000	2.7763	2.7759	+0.01
3	0.16234	9000	1.6337	1.6335	+0.01

The time was obtained directly in seconds from a magnetic counter operated from a pendulum clock. The calculated weights of silver given in the fifth column of the table were obtained by multiplying the number of coulombs by 0.00111800. This figure is the one agreed upon by the London conference (1908) as a secondary definition of the coulomb.

That accuracy of the kind shown in Table 1 depended upon the smooth functioning of the adjustment apparatus is shown by some experiments in which some part of it failed to work for a few seconds

at a time. The errors then increased, being, for instance, +0.02 and −0.03 on two occasions when relays failed to operate. On one occasion when the potential across R' was out of the range of the potentiometer for about 60 seconds, the error rose to 0.07%.

In the second series of determinations the connections were made as shown in Fig. 3 (b). The automatically adjusted resistance R was connected in series with another resistance R_1 of 960 ohms. These were in turn connected in series with a 150 volt storage battery, the coulometer, and the standard resistance R'. The resistance R_1 was of the screw adjustment type, and was so arranged that it could be made to throw a steadily increasing or decreasing resistance into the circuit through operation with a motor and reducing gear. The way this resistance was changed during each experiment is given, along with the other data, in Table 2. It will be seen that the accuracy

Table 2. Results of coulometer experiments. Large changes in resistance.

Experiment	Current (amperes)	Time (seconds)	Weight of silver deposit, grams		Per cent error
			Observed	Calculated	
4	0.12787	8404	1.2013	1.2014	−0.01
5	0.14265	7200	1.1481	1.1482	−0.01
6	0.14216	9506	1.5108	1.5108	0.00
7	0.10958	9000	1.1024	1.1025	−0.01

Experiment	*Change of resistance R_1 during experiment*
4	Increased to full value when reduced to zero.
5	Decreased from full value to zero then returned to full value.
6	Twice increased to full value from zero and returned to zero.
7	Steadily decreased from about half value.

obtained in the coulometer experiments is about the same with these arbitrary and relatively rapid changes of resistance in the circuit as with the slow changes encountered in the experiments outlined in Table 1. The fineness of the adjustments made by the apparatus was, however, limited to the potentials between adjacent turns of the rheostats R and R_1 of Fig. 3 (b). The deflections of the galvanometer were seldom if ever over 2 mm from this cause. The momentary values of the current thus varied about 0.07% from those given in the table. It seems entirely probable that if rheostats with an indefinite number of steps were used the adjustment at each second would have been as good as in the series of determinations outlined in Table 1. Such

rheostats are unfortunately not at present available. Adjustments for large changes of resistance in the circuit are, however, necessary in our work. It is evident from the coulometer experiments that the positive and negative errors due to irregularities in the rheostats cancelled out, on the average, within the experimental error.

In order to obtain the accuracy shown in the experiments described above it was necessary to obtain the best possible calibrations of the potentiometer P (Fig. 1) and of the resistance R'. The potentiometer P was of the Leeds and Northrup "Students" type. This was, however, calibrated against a "Type K" potentiometer made by the same firm. The individual coils of the latter were measured against a standard bridge, and the wire was calibrated by the internal method described by the makers. The resistance R', which had to carry larger currents than most coils are designed for, was made of No. 20 manganin wire and was immersed in oil. This coil needed frequent calibration since it had not had time to become properly aged. The Wheatstone bridge on which these measurements were made had recently been very carefully standardized, by the Carey-Foster method, against Bureau of Standards resistances, by Dr. Theodore Shedlovsky of this laboratory. The authors are indebted to Mr. Irving A. Cowperthwaite for assistance in constructing the apparatus.

SUMMARY

An apparatus is described for automatically maintaining a constant current through a circuit in which gradual increases and decreases of resistance and emf are occurring. Observation of the galvanometer indicated that the regulation was within 0.01 per cent in a circuit in which only small changes of resistance and emf occurred. The operation of the system over considerable periods of time was demonstrated by silver coulometer experiments in which an accuracy of 0.01 per cent was obtained.

With comparatively large changes of resistance in the circuit the momentary accuracy of adjustment was limited by the number of steps in the rheostats used. Experiments with the silver coulometer showed agreement within 0.01 per cent even when there were large increases and decreases of resistance in the circuit, indicating that the momentary errors in adjustment (never over 0.07%) cancelled each other on the average.

THE LABORATORIES OF
THE ROCKEFELLER INSTITUTE FOR MEDICAL RESEARCH,
NEW YORK, N. Y.

Handbuch der Experimentalphysik. Edited by W. Wien and F. Harm. Vol. XVIII: Wellenoptik und Polarisation, by K. F. Bottlinger, R. Ladenburg, M. V. Laue and Hans Schulz; Photochemie, by E. Warburg. pp. xiv+674. Akademische Verlagsgesellschaft, M. B. H., Leipzig. Paper, M 61.80; bound, M 63.50.

The general style and make-up of the volumes of this Handbuch which have previously appeared are so well known that detailed description of the present volume is unnecessary. It quite suffices, therefore, for purposes of this review, to give the contents. The following are the major divisions:

The Determination of the Velocity of Light in Bodies at Rest. (Ladenburg). pp. 34. A description of the various methods employed in the determination of this important quantity, from Römer to Michelson, giving the numerical values obtained by each.

Optics of Bodies in Motion. (Laue), pp. 68. A discussion of the various experiments from Bradley to the present time.

The Relativistic Frequency-shift and Deflection of a Beam of Light in the Gravitational Field of the Heavenly Bodies. (Bottlinger), pp. 10. A brief account, including some illustrative data.

The Reflection and Refraction of Light at the Boundary between two Isotropic Bodies. (Laue), pp. 86. Mainly theoretical.

Interference and Diffraction of Electromagnetic Waves, excluding x-rays. (Laue), pp. 154. A general discussion (with some excellent photographs of diffraction phenomena.)

Polarization of Light. (Schulz), pp. 104. Theory of polarization and a description of apparatus, and accessory equipment, for producing and studying polarized light.

Optics of Crystals. (Schulz), pp. 88. Propagation of light in crystals; interference phenomena; absorption.

Polarization of Light by Bodies without Regular Crystalline Structure. (Schulz), pp. 62. Double refraction; liquid crystals, Rotary polarization in isotropic bodies.

Photochemistry. (Warburg), pp. 40. A brief outline of the subject.

The book is well printed; contains many excellent diagrams and photographs of physical phenomena; and gives a wealth of references to original sources. Workers in optics will find it very valuable for both reference and study.

F. K. RICHTMYER

A LARGE RECIPROCATING C. T. R. WILSON CLOUD EXPANSION APPARATUS

By Gordon L. Locher

The apparatus described in this paper was designed especially for some statistical investigations of the paths of electrons ejected by x-rays in gases. For this purpose it is desirable to use a C. T. R. Wilson cloud apparatus arranged for stereoscopic photography and embodying the following characteristics:

1. *Large diameter of cloud chamber*, in order to have space for as many electron tracks as possible without crowding, and to accomodate the long tracks produced by hard x-rays.

2. *Rapidity and the utmost simplicity of operation.* The amount of time and effort saved by use of a simple apparatus during the course of an investigation which involves the making of several thousands of pairs of photographs may be very considerable. The Shimizu-Wilson type of apparatus is far superior to the usual non-reciprocating type, in this respect.

3. *Exact duplication of the cycle of operations through many cycles*, in order to secure uniformity of results.

4. *Easy and exact control of the expansion ratio of the gas in the cloud chamber and of the speed of expansion.* The adjustment of the expansion ratio is much more critical for good electron tracks than for alpha-ray tracks, hence it must be adjustable in very small steps. The density of the tracks is largely determined by the speed of expansion and the expansion ratio. It is desirable to have the droplets along the tracks as large and numerous as possible. Of course the number of drops per centimeter path is proportional to the pressure of the gas in the chamber if every ion along the path becomes the nucleus of a drop; but if the speed of expansion is not at its best value, the first ions on which condensation takes place seem to get most of the supersaturated vapor in the region condensed upon them while the other ions get little or none at all. This makes the drops coarse and the tracks discontinuous. If the expansion of the gas is too rapid, or too great, a general cloud will form, apparently without any neuclei for the drops.

5. *Freedom from leakage.* Leakage of air into the cloud chamber is a serious source of difficulty because it introduces dusty air on which condensation takes place after expansion, thus robbing the ion-centered

drops. Also, a stream of air entering through even a very small opening causes a turbulence in the chamber that distorts or destroys the electron tracks.

6. *Automatic operation of the timing devices for the various associated operations*, such as flashing the x-rays, operation of the cameras, illumination, etc.

The machines described herein fulfill these requirements very well. In their construction the rotary drive arrangement, first made use of by Shimizu, (Shimizu, Roy. Soc. Proc., *99*, p. 425; 1921) is employed in a modified form. It appears that no large cloud apparatus suitable for investigation of x-ray photo-electron tracks, and using this principle, has ever been built before, in spite of the great advantages of its speed and simplicity of operation. In fact, the reciprocating principle seems hitherto to have been confined exclusively to small apparatus.

Two of these apparatus have been constructed. They do not differ in principle, and the first, designed and constructed at the Rice Institute, will be described in some detail. Points of difference between this and the second machine, constructed at Miami University, will be mentioned later.

Fig. 1 shows the general construction of the apparatus. An outstanding feature is that the gas in the chamber, C, is compressed by bending a heavy rubber-and-canvas diaphram, D, instead of using a piston sliding in a cylinder. The diaphram separates two brass castings, B_1 and B_2, between which it is tightly bolted with nine heavy bolts. The space V, below the diaphram, is connected with a ten-gallon bottle through a rubber tube of large diameter. The pressure in the bottle, hence in V, can be adjusted to any desired value by a pump. Above the diaphram is a chamber, W, which is filled with water. A float, F, on top of the water column forms the bottom of the cloud chamber, C, which is a thick-walled pyrex cylinder covered with a clear plate glass disc; a brass ring and six brass bolts hold the chamber firmly to the upper casting. The paraffin float moves up and down with the water as the diaphram is bent and prevents splashing and waves on the surface of the water. It is covered with black felt which serves the double purpose of a photographic background and a wick to help saturate the air in the chamber; a central guide under the water keeps the float centered.

The chamber has an internal diameter of 14 cm and a height of 4.5 cm; the wall thickness is about 6 mm. Pictures of the electron tracks are

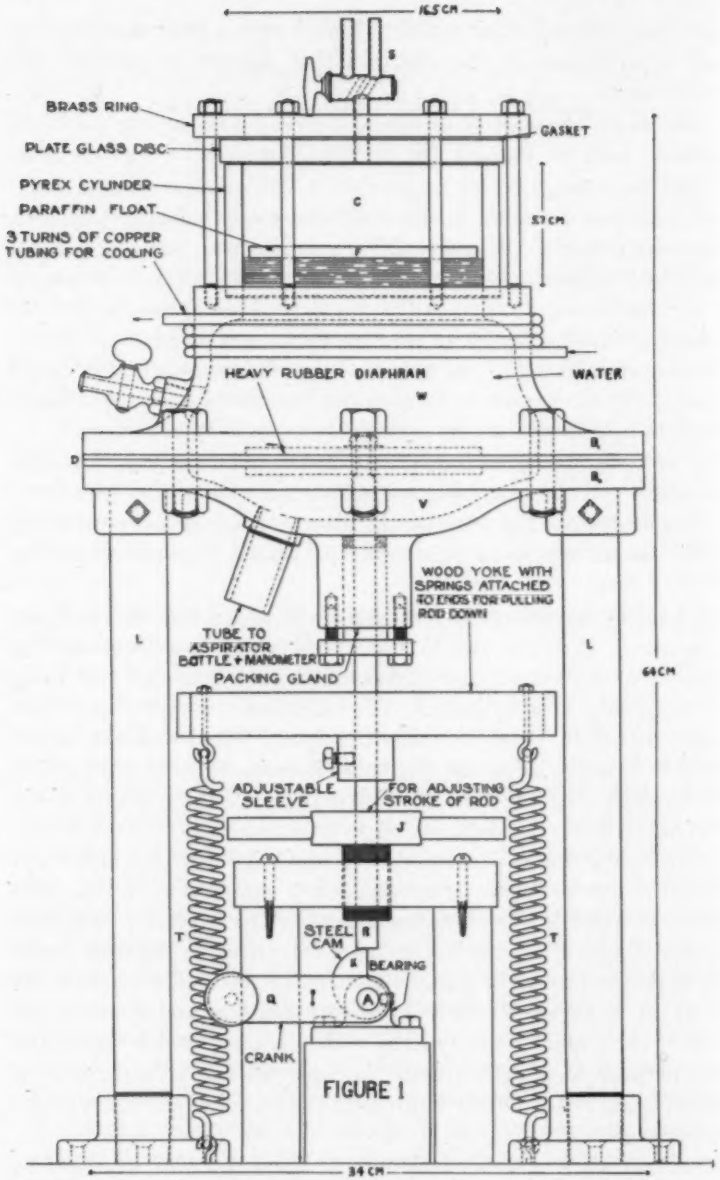
16.5 CM
S
BRASS RING
GASKET
PLATE GLASS DISC
PYREX CYLINDER
C
5.7 CM
PARAFFIN FLOAT
3 TURNS OF COPPER TUBING FOR COOLING
HEAVY RUBBER DIAPHRAM
W
WATER
B
B'
D
V
WOOD YOKE WITH SPRINGS ATTACHED TO ENDS FOR PULLING ROD DOWN
TUBE TO ASPIRATOR BOTTLE + MANOMETER
PACKING GLAND
L
L
64 CM
ADJUSTABLE SLEEVE
FOR ADJUSTING STROKE OF ROD
J
T
T
STEEL CAM
R
E
BEARING
Q
A
CRANK
FIGURE 1
34 CM

FIG. 1.

taken from above through the glass cover. An excellent leak-free seal between this cover and the cylinder is made by coating the edge of each with "Duco" brush lacquer and clamping them together without a gasket; a similar seal, except with the use of a thin rubber gasket, is used between the cylinder and the brass casting. The lacquer does not shrink, as waxes do, and additional coats may be applied with a brush to prevent leakage.

Gases may be introduced into the chamber by means of two stop-cocks, *S*, of 1 mm bore, sealed through the top of the chamber at the extremities of a diameter. A manometer, semi-permanently connected to one of these, makes it possible to measure the pressure in the chamber and to calculate the expansion ratio of the gas, as well as to detect leaks. Distillation of water onto the top and walls of the chamber is prevented by cooling the castings with a stream of cold water or by directing a beam of radiant heat from a small electric heater toward the top of the apparatus, or both. The exposed metal parts are painted with aluminum paint to minimize absorption and radiation.

The manipulation of the machine is very simple. When it is adjusted, the operator has only to rotate the crank, *Q*. This turns a special cam, *K*, moving the drive-rod, *R*, which communicates its motion directly to the diaphram, *D*, to which it is fastened by two brass plates. Subsequent to the greatest compression of the gas in the chamber, a sudden expansion occurs when a jump in the cam is reached. The maximum possible displacement of *R* is the height of the step in the cam, or 1.9 cm. But due to the large area of the diaphram, a much smaller displacement is always sufficient, so the expansion is stopped when a collar fastened to the drive-rod strikes the adjustable guide, *J*. The position of *J* can be varied in infinitesimal steps, hence the expansion ratio of the gas, which is of the order of 1.28/1 under ordinary conditions.

The speed of expansion is controlled by two things: the pressure in the chamber, *V*, and the tension of two spiral springs, *T*. The latter is suitable for coarse adjustment and the former for fine. The expansion speed can be made subject to very accurate control by varying the pressure in *V*, which is ordinarily maintained at 5 to 8 cm below that in *C*. In practice it is found desirable to let the gas remain compressed for about 20 seconds before expanding, in order to establish thermal equilibrium, because of the poor conductivity of the walls of the chamber. This pause can be used for changing plates in the cameras in preparation for the next exposure.

A potential difference of about 150 volts is maintained in the chamber during the compression of the gas, between a fine platinum wire stretched near the top of the chamber, and the water. This sweeps out the ions and prevents a general cloud. Just after the expansion, four operations occur in quick succession:

1. The electric field in the chamber is cut off.
2. X-rays are sent in through the side of the chamber after passing through suitable openings and filters.
3. A bright light enters the chamber from the opposite direction, illuminating the electron tracks.
4. A stereoscopic photograph is taken by two cameras above the chamber.

These operations are carried out by four special commutators mounted on the same shaft, *A*, as the cam. They are arranged by trial to give the best time intervals between the operations; these mechanisms are then automatic and require no more attention. The first commutator maintains the electric field in the chamber during the compression half of the cycle and grounds the collector during the other half. The second commutator momentarily closes a magnetic contactor switch in the primary of the x-ray transformer. The third controls the illumination and the fourth the camera shutters.

A beam of light sent through the chamber along the path of the x-rays, comes from a 110-volt a. c. arc; the photographic cored carbons used in this arc furnish rich and intense illumination with a current of 20 amperes. At the instant of taking the photographs, however, the rheostat in the line is momentarily short-circuited by a heavy contactor switch, controlled by the third commutator, allowing the current to rise very greatly. The illumination then increases enormously. Sixty ampere fuses in the circuit seldom burn out if the current only flows for 1/25 second or less. The arc does not go out and the process can be repeated rapidly. This seems to be an excellent way to obtain an intense light for many other photographic purposes. The photoelectric effect of the light on the gas in the chamber produces a great many stray ions, hence, it is found necessary to employ a shutter, between the arc and the chamber, which only opens for an instant while the photographs are being taken. This also minimizes convection currents.

The intensity of light scattered by water droplets at right angles to the direction of illumination is exceedingly small, even when they are strongly illuminated. This makes it necessary to use camera lenses

of large aperture and very rapid photographic plates. The cameras in use are Zeiss instruments, the model being the Ica Ideal B with Compur shutters and F: 4.5 Tessar lenses, especially matched for stereoscopic work. These are operated with the lenses at a height of 28 cm above the top of the chamber; the shutters are tripped by a solenoid controlled by the fourth commutator. Hammer Press Plates, which have a fine grain and are very fast, are used successfully. Owing to the shortness of the distance between the cameras and the tracks, it was not found feasible to use a single stereo-camera. The optic axes of the cameras in use intersect at the object.

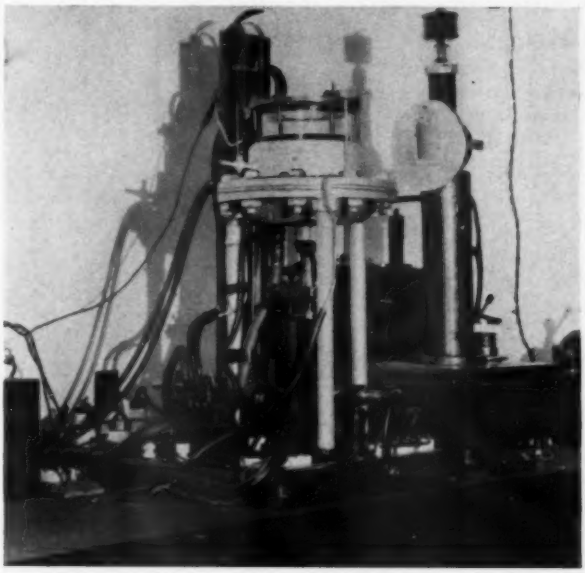

FIG. 2. *This shows the arrangement of the cloud-apparatus, x-ray tube and pressure controls.*

The second apparatus, built by the writer at Miami University, is shown without the arc or x-ray shielding, in Fig. 2. It differs from the one described above in having a slightly larger chamber: 15.7 cm in diameter and 5.7 cm in height. The commutators are somewhat less elaborate than those in the first apparatus. This machine is to be equipped with matched Leitz roll-film cameras (Leica No. 35015) which have F: 3.5 lenses and take pictures on panchromatic motion picture film. The lenses have about 65 per cent more light-gathering

power than F: 4.5 lenses, which reduces the requirements of the intensity of illumination. For stereoscopic examination and measurement of the pictures obtained, the images will be projected side by side on a screen, by two projectors.

The operation of these apparatus seems highly satisfactory and they are adaptable for numerous investigations of various phenomena of x-rays and radioactivity.

The project involving the construction of the apparatus, and many of the features of the machines themselves were suggested by Professor H. A. Wilson, of Rice Institute, for whose many valuable suggestions and interest I wish to express my appreciation.

THE RICE INSTITUTE,
HOUSTON, TEXAS; AND
MIAMI UNIVERSITY,
OXFORD, OHIO,
APRIL 11, 1929.

A MERCURY ARC WITH THIN GLASS WINDOW

By Simon Sonkin

Thin glass windows have been used for the transmission of soft x-rays by Professor Davis and his students, and for Lenard rays by Slack,[1] so that the application to the transmission of ultraviolet radiation is a logical step.

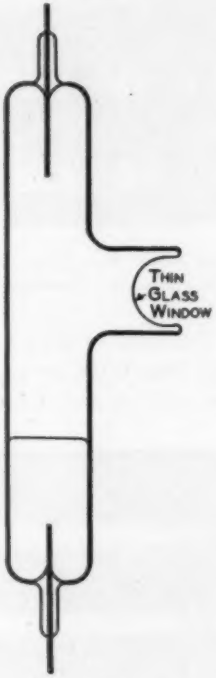

Fig. 1.

Several pyrex mercury arcs were built with thin pyrex windows, as shown in Fig. 1. The spectrum obtained from such an arc is shown in Fig. 2. together with the spectrum from a Cooper-Hewitt quartz arc carrying the same current, and the spectrum of the arc as obtained through the thick tubing wall (1 mm). It will be seen that nothing below about λ2900 is transmitted through the wall, whereas through the

[1] J.O.S.A., & R.S.I., *18*, pp. 123–126; 1929.

thin window the transmission goes well below λ2400, (the plates show transmission below λ2300) and compares quite well with the quartz arc.

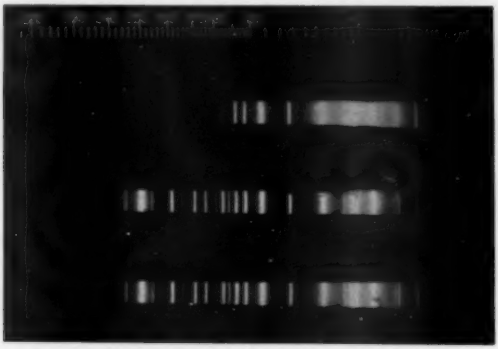

FIG. 2. *Mercury arc—through 1 mm pyrex. Mercury arc—through thin pyrex window. Mercury arc—Cooper-Hewitt quartz arc. Exposure time—5 seconds.*

Several arcs were built with the thin windows extending into the arc stream, and in these cases the lines λ1950 and λ1849 could be seen on the plates. The thin windows of these arcs, however, would collapse if

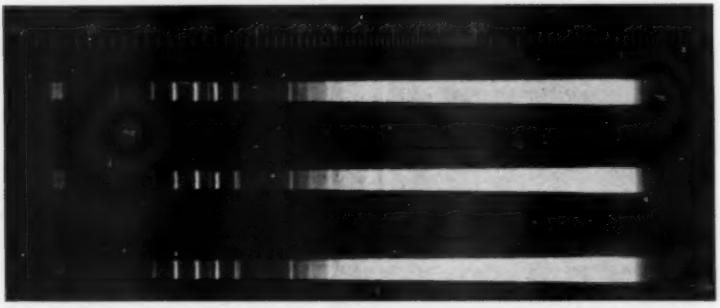

FIG. 3. *A—Zinc-aluminum spark. B—Zinc-aluminum spark through 1 mm fused quartz. C—Zinc-aluminum spark through .001 cm pyrex window. Exposure—30 seconds.*

the arcs were run continuously for any great length of time, but no such difficulty is encountered with the thin window in a side tube as in Fig. 1.

To investigate the transmission of these windows, a zinc aluminum spark was used. Fig. 3. shows the spark spectrum; the transmission of

a piece of fused quartz 1 mm thick; and the transmission of a pyrex window .001 cm thick.

It will be seen that the pyrex window transmits out as far as λ1854, though not quite so well as fused quartz.

Such pyrex windows should therefore prove quite useful for photoelectric cells, sensitive to the ultraviolet, and may also eliminate to some extent the cementing on of quartz windows to glass tubes; and for ordinary spectroscopic work a pyrex arc of the type described should prove an inexpensive substitute for the quartz arc.

COLUMBIA UNIVERSITY,
NEW YORK, N. Y.,
MARCH 29, 1929.

Speech and Hearing. By Harvey Fletcher, Director of Acoustical Research at the Bell Telephone Laboratories. xv+331 pp. D. Van Nostrand Company, Inc. New York. $5.50, net.

This important book presents some of the results of an extensive study of speech and hearing, carried out by the author and his collaborators at the Research Laboratories of the Bell Telephone Company. Although these researches were initiated "to obtain the fundamental facts on which to base the design of apparatus and systems for telephone use," yet, as was perhaps to be expected, the results have found important applications in other branches of both pure and applied science.

The book is divided into four parts: I, Speech; II, Music and Noise; III, Hearing; and IV, The Perception of Speech and Music. Each part is suitably subdivided into chapters. In part I are found such topics as the mechanism of speech; classification of speech sounds; methods of recording speech waves, with numerous examples of the wave forms of complete words; theories of vowel production; speech power, including much illustrative data; and a study of the relative frequency of occurrence of the different sounds used in conversational speech.

Part II contains two short, but very interesting, chapters on Physical Properties of Musical Sounds and Noise. Numerous curves and diagrams show the wave form and "acoustic spectra" of typical musical sounds from both voice and instruments.

Part III, on Hearing, contains six chapters, viz: The Mechanism of Hearing; Limits of Audition (for both intensity and frequency); Minimum Perceptible Differences in Sound; Masking Effects (of one sound on another); Binaural Beats (and other binaural pheonomena); and Methods of Testing the Acuity of Hearing.

Part IV describes the elaborate experiments undertaken to ascertain the various factors affecting the perception of both speech and music. These studies include: the loudness of pure tones and of complex sounds; the recognition of pitch in musical tones; the recognition of speech sounds, including the effects of various types of distortion; and the effect of noise and deafness.

One does not know which to admire more: the very lucid way in which Dr. Fletcher has presented this exceedingly complex subject; or the skill and ingenuity which he and his collaborators have shown in carrying out these difficult investigations. Not only will a wide circle of readers find this book interesting, but it should do much to stimulate research in a somewhat neglected field.

F. K. RICHTMYER